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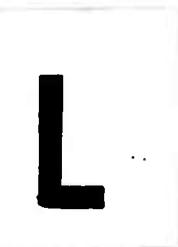
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# Adaptation of the Kift-Fooks Ionospheric Ray-Tracing Technique to a High-Speed Digital Computer

by

Douglas E. Westover and Lawrence A. Roben

October 1963

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RADIOSCIENCE LABORATORY  
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ADAPTATION OF THE KIFT-FOOKS  
IONOSPHERIC RAY-TRACING TECHNIQUE  
TO A HIGH-SPEED DIGITAL COMPUTER

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Radioscience Laboratory  
Stanford Electronics Laboratories  
Stanford University              Stanford, California

## ABSTRACT

This report describes a modified ray-tracing technique used in the synthesis of oblique-incidence, step-frequency ionograms. Ionograms of this type are obtained experimentally to aid in the real-time selection of frequencies for point-to-point communications and propagation studies. When it is desirable to identify the modes of propagation, computer-calculated ray tracings have proved quite valuable.

The Kift-Fooks ray-tracing technique was chosen because it is a rapid program capable of tracing rays when only a minimum of ionospheric data is available. One could utilize this technique in the analysis of propagation data either by synthesizing an oblique-incidence ionogram for direct comparison with experimentally observed results or by comparing plots of maximum usable frequency (predicted) with receiving-station log sheets. The details of the computer program are included with instructions that may be used as a guide by anyone familiar with computers and programming operations to perform his own calculations.

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## LIST OF SYMBOLS

- d distance to any point along the great-circle path  
f frequency  
 $f_h$  gyro frequency  
 $f_o$  critical frequency of a layer  
 $f_o^E$  FOE = critical frequency of the E layer  
 $f_o^{F1}$  FOF1 = critical frequency of the F1 layer  
 $f_o^{F2}$  FOF2 = critical frequency of the F2 layer  
 $f_o^{ES}$  FOES = critical frequency of the ES layer  
h height  
 $h_o$  height at the bottom of a parabolic layer  
 $h_r$  height of reflection  
 $h_m$  height of the maximum electron density of a layer  
 $h_m^E$  height of the maximum electron density of the E layer  
 $h_m^{F1}$  height of the maximum electron density of the F1 layer  
 $h_m^{F2}$  HT FOF2 = height of the maximum electron density of the F2 layer  
i angle between ray path and vertical at any point along the path  
p' time delay  
x ratio of the F2 4000 MUF to the  $f_o^{F2}$   
D distance ray propagates  
DB attenuation due to D-layer absorption  
F2 4000 MUF maximum usable frequency for 1-hop F2-layer propagation  
LOF lowest observed frequency  
MOF maximum observed frequency  
M3000 ratio of the F2 3000 MUF to the  $f_o^{F2}$   
N number of ray passages through the D layer

R radius of the earth  
SSN sunspot number  
T time in hours (universal time)  
 $y_m$  semi thickness of a parabolic layer  
 $y_m^E$  semi thickness of the parabolic E layer  
 $y_m^{Fl}$  semi thickness of the parabolic Fl layer  
 $\alpha$  bearing of receiver from transmitter (degrees East of North)  
 $\beta$  take-off angle (above the horizon)  
 $\theta_0$  longitude of transmitter  
 $\theta_1$  longitude of point on path  
 $\theta_2$  longitude of the sun  
 $\lambda_0$  latitude of transmitter  
 $\lambda_1$  latitude of point on path  
 $\lambda_2$  declination of sun  
 $\phi_0$   $\phi_0$  = angle of incidence, measured from vertical, at the bottom of the ionosphere  
 $\phi_r$   $\phi_r$  = angle of incidence, measured from vertical, at the real height of reflection  
 $\phi_D$   $\phi_D$  = angle of incidence, measured from vertical, at the bottom of the D layer  
 $\chi$  solar zenith angle  
 $\Delta$  take-off angle (above the horizon)  
 $\Delta D$  ground distance for a ray passing through a layer  
 $\Delta P'$  virtual distance along a ray passing through a layer

ACKNOWLEDGMENTS

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## I. INTRODUCTION

In an effort to understand better the propagation characteristics associated with fixed-frequency transmissions over a long (8000-km), east-west path (i.e., Hawaii to Massachusetts), it was decided to instrument this path with a step-frequency (4.64-Mc) transmitter and a synchronized receiver. With the above equipment operating on a round-the-clock basis, it was hoped that records could be obtained that would permit deduction of the mode structure and apparent ray path of the propagating signals.

Examination of the records taken on this path, soon indicates that the usual simplifying assumptions (such as a uniform ionosphere over the entire path) are often not representative of what is happening. The path, 8000 km long, is just on the edge of the normally assumed "allowable" two-hop, F2-layer propagation. Records show that the 2F2 mode propagates for only short periods around noon and midnight, local time, at the midpoint of the path. At other times (especially sunrise and sunset), the progressive change across the path from a daytime ionosphere (with E, F1, and F2 layers) to a nighttime ionosphere (F2 layer only) produces a bewildering variety of propagation modes. Analysis soon becomes fairly complex. To assist in the understanding of the mode structure, it was felt that a ray-tracing program that simulated the experimental data would help.

Familiarity with the experimental technique and record form will help in understanding the type of information that would be desirable from computed ray tracings. The experimental data were obtained in the following way. The transmitter and receiver include electronically tuned and synchronized circuitry that ranges in frequency from 4 to 64 Mc in 160 steps. 40 linearly spaced steps per octave band. Pulses, 50~~usec~~ in duration, are transmitted over the Hawaii-

Massachusetts path, and the received pulses (differentially delayed in time as a result of the different modes of propagation) are recorded on film using the following technique. An oscilloscope is intensity modulated with the detected video output of the receiver. As the transmitter and receiver step in frequency over the operating range, the display is recorded on moving film, producing a record showing time delay as a function of frequency. This presentation is referred to as an oblique-incidence ionogram. An artist's sketch of this type of record is shown in Fig. 1.

The primary characteristics that one would hope to obtain from a ray-tracing analysis for comparison with the experimental results are summarized below:

1. The Maximum Observed Frequency (MOF) and the Lowest Observed Frequency (LOF) for each of the modes (e.g., mode 1,2,3,...).
2. The differential group time delay separating each of the modes at any given frequency (e.g.,  $f_1$ ).

In addition, it would be desirable to obtain a profile view of the propagation path showing the rays, their ground-reflection points and the apparent path of the rays through the ionosphere. An example of this is given in Fig. 2, showing the three modes of the ionogram of Fig. 1, at a fixed frequency  $f_1$ .

## II. AVAILABLE RAY-TRACING TECHNIQUES

The problem in synthesizing an oblique-incidence ionogram by a ray-tracing approach is actually twofold:

1. Can the mode structure be duplicated by a ray-tracing approach if sufficient ionospheric data are available?
2. In the absence of this ionospheric data, could the CRPL ionospheric-propagation predictions, available three months in advance, be used in conjunction with the ray-tracing program to predict the mode structure likely to be observed?

With this problem in mind, it was decided first to find out how other researchers had solved this or similar problems. Inquiry into the available ray-tracing techniques necessitated visiting various establishments to find out the latest information; at that time, much of it was as yet unpublished. However, since then, a meeting has been held in Lindau, Germany, to discuss oblique-incidence soundings and ionospheric ray tracing.

Table 1\* is a summary of ray-tracing techniques.

An alternate possibility, the use of an analog computer to solve the ray-tracing equations, has been utilized by Wong [Ref. 17]. The difficulty in using an analog computer is that the output, height vs range (as a function of frequency), gives the distribution of energy along the great circle but does not "home-in" on the receiver (a point at a fixed range).

\* This information is based on material that appeared in the "Report of the Lindau Meeting on Oblique Sounding of the Ionosphere," May 6-10, 1963. Meeting held at: Institut Für Ionsphären-Physik, Max-Planck-Institut Für Aeronomie, Lindau Über Northeim, Germany.

TABLE I. RAY-TRACING TECHNIQUES

<u>Class</u>	<u>Assumptions</u>	<u>Advantages</u>
Equivalence Method	Plane earth; plane ionosphere; no magnetic field. [Ref. 1]	Extreme simplicity, enabling one to obtain an order-of-magnitude calculation of time delay and distance even when no ionogram is available; useful on short paths.
	Plane earth; plane ionosphere. [Ref. 2]	Allows determination of effects of earth's magnetic field.
Overlay Methods	Concentric layers with no magnetic field; empirically corrected, however, angle curves are based on Martin's equivalence theorem. [Ref. 3]	Enables use of a slider in calculating apparent ray paths. Use of sliders in scaling the M3000 factor from vertical incidence ionograms is important since these data are used by CRFL in their prediction techniques.
	Concentric layers. [Ref. 4]	Corrects for magnetic field in generating a slider for any given ionospheric profile; particularly useful in analyzing long-distance propagation paths with low angles of elevation.
Inverse Slider	Same as that of slider used. [Ref. 5]	Inverse slider technique enabling quick identification of the modes on an oblique-incidence ionogram and the vertical incidence ionogram, at the path midpoint, to be determined.
Concentric ionosphere	Parabolic layers; no magnetic field. [Ref. 6]	Reference to the published ionograms provides a simple method of ray tracing in a parabolic layer.
	Synthesis of ionospheric profiles with line segments. [Refs. 7, 8, 9]	Profile may be accurately represented.

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Class

Assumptions

Approximately constant magnetic field; can use any profile as above [Ref. 10]  
parabolic layers: no magnetic field; constant ratio for y in the other layers;  
fixed  $f_{OE} = 1.4$  for  $\lambda \leq 7.0$ ; otherwise,  
 $f_{OE} = 3(\cos \chi)$  [refs. 11,12]

Advantages

A general expression is developed enabling direct calculation of the ray-path length using a simple ray treatment.

By assuming concentric ionosphere for each hop but calculating each layer as it is first encountered, one can include first-order effects of a horizontal gradient in electron density; homing-in on the receiver is provided, allowing rapid calculation to identify modes of propagation and to predict MUF's and ray paths from the CRPL predictions.

Same as above [Ref. 13]

isotropic ionosphere

\*

isotropic sources  
- dimensional

\*

Hazelgrove equations  
[Ref. 14]

\*

tilting mirror reflector  
in the ionosphere; Faraday's  
equivalence theorem [Ref. 15]

tilting  
dimensional

\*

Inclusion of tilts by correction of  $\phi$  at entry into and exit from the layers may give a refinement to the method described above.

The ray path can be approached more realistically, thus providing more accurate ray paths in the regions of extreme tilts or gradients along the great circle.

Gives a first-order approximation to super-modes and off-great-circle-path propagation. Nomograms are available for some heights and distances; others can be calculated and plotted by use of a 7090 computer.

Most thorough analysis when ionospheric can be specified in great detail; has homing-in feature incorporated.

Hazelgrove equations  
[Ref. 16]

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The "home-in" capability afforded by a digital-computer program is an attractive feature. Sorting by modes and range discrimination greatly simplifies the handling of the enormous amounts of data that are calculated by the computer. One is thus able to concentrate on the path in question, having already sorted out the rays that never reach the receiver.

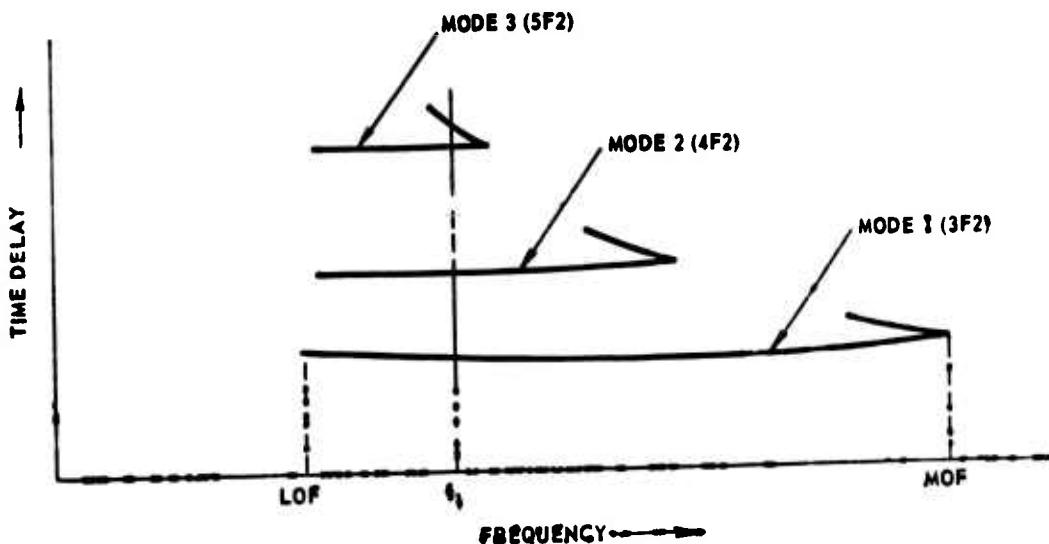


FIG. 1. THEORETICAL VERSION OF AN OBLIQUE-INCIDENCE, SWEEP-FREQUENCY IONGRAM.

### III. CHOICE OF THE KIFT-FOOKS TECHNIQUE

To synthesize an oblique-incidence ionogram (Fig. 1), it is necessary to consider only those rays that reach the receiver. Detailed knowledge of the ionosphere is not always available and, where predictions are concerned, a detailed ray-tracing approach is not justified. In fact, most of the time, only a bare minimum of data exists concerning the true electron-density profile along any given path. Even with electron-density distributions, assumptions as to the structure of the magnetic field, the off-great-circle profiles, as well as a choice of a magneto-ionic theory, need to be made prior to the use of a complete three-dimensional analysis [Ref. 16].

With these limitations, it was believed that a program which takes into account the gross changes in the ionosphere along a path at sunrise and sunset, by the inclusion of the daytime E and F1 layers and a specularly reflecting sporadic E layer, would suffice.

The major factors governing the choice of the Kift-Fooks technique were probably the rapidity with which the program could be run on a truly high-speed digital computer (either the IBM7090 or the IBM 7094) and the fact that predictions could be made, using the CRPL ionospheric propagation-predictions in their present card format [Ref. 18], on a highly automated basis.

Thus, it was decided to use the ray-tracing technique suggested by Kift [Ref. 11] and programmed for use on the Pegasus computer by Fooks [Ref. 12]. The advantages of this program are that it assumes a set of parabolic layers for the ionospheric profile and then calculates the ray path in (or through) a parabolic layer by the Appleton-Beynon [Ref. 6] equations.

Some of the inaccuracies of this technique are pointed out by Kift at the end of his article, with reference to the work of Vickers [Ref. 19]. A report that compares the Kift-Fooks technique with a more accurate technique, developed by Croft [Ref. 20], is soon to be published as another report in this series.

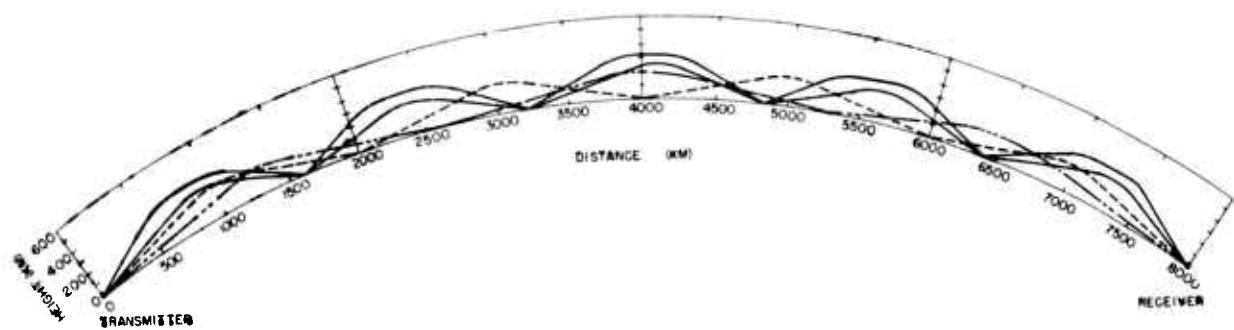


FIG. 2. CROSS SECTION OF IONOSPHERIC RAY PATHS.

#### IV. HOW TO UTILIZE THE KIFT-FOOKS TECHNIQUE

Before attempting to utilize the Kift-Fooks technique in the analysis of point-to-point propagation characteristics, one should know what data are available in the print-out of the program and how to use these data.

Table 2 lists the ionospheric-profile parameters along the great-circle path (from the transmitter to the receiver) in 100-km intervals. The values given are the critical frequencies of the E, F1, and F2 layers, and the height at which the maximum of the F2 layer occurs is given for the points mentioned above. Details of the exact computer output format (Tables 2,3,4) are given on pp. 11, 12, and 13.

Each ray-tracing group is identified by the transmitter latitude and longitude, the bearing to the receiver, and the time, month, and year for which the ionosphere was compiled.

An example of the present data format is given in Table 3. The description of each mode includes: names of successive reflecting layers, frequency, take-off angle, group time delay, and attenuation. The terminology used in this format is different from that recommended for use in oblique-incidence work (Appendix A). However, since this report is intended to explain the ray-tracing program in its present form, inclusion of the recommended nomenclature would have necessitated further delays.

The modes are listed in terms of increasing frequency and take-off angle (for any one frequency).

In addition, an option available to the program prints out the ground range and height of the ray for points of entry or exit of a layer and the ground-reflection points (Table 4). Thus a ray plot similar to that shown in Figure 2 could be plotted from the data of Table 4.

With knowledge of the output format in hand, one can now proceed with the discussion of how these data can be

used in the synthesis of an oblique-incidence ionogram (Fig. 1). Referring to Table 3 and establishing the same set of coordinates as that achieved experimentally, one would then plot and join together points having the same mode description (i.e., .F1 .E .E .E .E). This plot could then be compared directly with the experimentally achieved data. Please note, however, that there will be an omission of the high-angle rays because of the method used in programming the computer for mode calculation and retention.

When the take-off angle and the attenuation associated with a given mode are taken into account, a first-order approximation can be made to eliminate many of the predicted modes that experience tells us just wouldn't get through.

Using vertical-incidence soundings made along or near the great circle, as a first-order correction to the CRPL prediction, enables greater accuracy to be achieved, particularly if patches of sporadic E are present which were not taken into account in the predictions. A subsequent report will be issued outlining the procedure used in this case (i.e., an after-the-fact analysis).

However, it is most important to emphasize once again the main advantage of the Kift-Fooks technique as a predictor of propagation conditions. Certainly, when detailed information regarding the ionospheric profile is available, it would make sense to utilize one of the more detailed ray-tracing programs currently available [Refs. 9,14,16,20].

By directly converting the CRPL ionospheric propagation predictions into values of  $f_o F2$  and M3000 (the ratio of the 3000 Km MUF to the  $f_o F2$ ) and subsequently using the assumption of Kift and Fooks [Refs. 11 and 12, respectively], the computer can calculate the values of height of the maximum of the F2 layer and trace all subsequent rays that reach the receiver.

Thus we have a highly automated prediction program, the details of which are specified in the following sections.

TABLE 2. IONOSPHERIC-PROFILE PARAMETERS

IONOSPHERIC PROFILE FOR 6 OCTOBER 1962 1737.36 CUT PATH/SEDIMENT PATH						2.9	4.0	7.0	132.37	2400.00	3.1	4.4	7.7	250.19	5803.00
F0E	F0F1	F0F2	HT	F0F2	RANGE	2.9	4.0	7.0	2900.00	2900.00	3.1	4.4	7.7	252.39	5900.00
2.83	4.6	7.5	205.55	0.		2.9	4.9	7.5	230.27	3500.00	3.1	4.4	7.7	254.49	5000.00
2.84	4.6	7.5	207.13	100.00		2.9	4.9	7.5	230.27	3500.00	3.1	4.4	7.7	254.49	5000.00
2.85	4.6	7.5	208.93	250.30		2.9	4.1	7.5	229.14	3120.00	3.1	4.4	7.8	255.48	5100.00
2.86	4.6	7.5	210.77	300.09		2.9	4.1	7.5	227.34	3225.00	3.1	4.4	7.8	256.35	5200.00
2.87	4.6	7.5	213.23	400.00		2.9	4.1	7.5	224.86	3370.00	3.1	4.4	7.8	260.13	5300.00
2.88	4.6	7.5	215.73	500.00		2.9	4.1	7.5	224.86	3400.00	3.1	4.4	7.8	261.79	5400.00
2.89	4.6	7.6	218.45	600.00		2.9	4.1	7.5	221.76	3470.00	3.1	4.4	7.8	264.74	5500.00
2.90	4.6	7.6	221.99	700.00		2.9	4.2	7.5	216.39	3500.00	3.1	4.4	7.8	266.79	5600.00
2.91	4.6	7.6	224.57	800.00		2.9	4.2	7.5	214.57	3520.00	3.1	4.4	7.8	268.86	5700.00
2.92	4.6	7.6	229.28	900.00		2.9	4.2	7.5	213.27	3550.00	3.1	4.4	7.8	270.93	5800.00
2.93	4.6	7.6	233.33	1000.00		2.9	4.2	7.5	212.77	3570.00	3.1	4.4	7.8	273.00	5900.00
2.94	4.6	7.6	236.64	1100.00		2.9	4.2	7.5	212.77	3600.00	3.1	4.4	7.8	275.07	6000.00
2.95	4.6	7.6	239.19	1200.00		2.9	4.2	7.5	212.77	3620.00	3.1	4.4	7.8	277.14	6100.00
2.96	4.6	7.6	241.61	1300.00		2.9	4.2	7.5	212.77	3640.00	3.1	4.4	7.8	279.21	6200.00
2.97	4.6	7.6	242.92	1400.00		2.9	4.2	7.5	212.77	3660.00	3.1	4.4	7.8	281.28	6300.00
2.98	4.6	7.6	243.33	1500.00		2.9	4.2	7.5	212.77	3680.00	3.1	4.4	7.8	283.35	6400.00
2.99	4.6	7.6	243.74	1600.00		2.9	4.2	7.5	212.77	3700.00	3.1	4.4	7.8	285.42	6500.00
3.00	4.6	7.6	244.15	1700.00		2.9	4.2	7.5	212.77	3720.00	3.1	4.4	7.8	287.49	6600.00
3.01	4.6	7.6	244.56	1800.00		2.9	4.2	7.5	212.77	3740.00	3.1	4.4	7.8	289.56	6700.00
3.02	4.6	7.6	244.97	1900.00		2.9	4.2	7.5	212.77	3760.00	3.1	4.4	7.8	291.63	6800.00
3.03	4.6	7.6	245.38	2000.00		2.9	4.2	7.5	212.77	3780.00	3.1	4.4	7.8	293.70	6900.00
3.04	4.6	7.6	245.79	2100.00		2.9	4.2	7.5	212.77	3800.00	3.1	4.4	7.8	295.77	7000.00
3.05	4.6	7.6	246.20	2200.00		2.9	4.2	7.5	212.77	3820.00	3.1	4.4	7.8	297.84	7100.00
3.06	4.6	7.6	246.61	2300.00		2.9	4.2	7.5	212.77	3840.00	3.1	4.4	7.8	299.91	7200.00
3.07	4.6	7.6	247.02	2400.00		2.9	4.2	7.5	212.77	3860.00	3.1	4.4	7.8	301.98	7300.00
3.08	4.6	7.6	247.43	2500.00		2.9	4.2	7.5	212.77	3880.00	3.1	4.4	7.8	304.05	7400.00
3.09	4.6	7.6	247.84	2600.00		2.9	4.2	7.5	212.77	3900.00	3.1	4.4	7.8	306.12	7500.00
3.10	4.6	7.6	248.25	2700.00		2.9	4.2	7.5	212.77	3920.00	3.1	4.4	7.8	308.19	7600.00
3.11	4.6	7.6	248.66	2800.00		2.9	4.2	7.5	212.77	3940.00	3.1	4.4	7.8	310.26	7700.00
3.12	4.6	7.6	249.07	2900.00		2.9	4.2	7.5	212.77	3960.00	3.1	4.4	7.8	312.33	7800.00
3.13	4.6	7.6	249.48	3000.00		2.9	4.2	7.5	212.77	3980.00	3.1	4.4	7.8	314.40	7900.00
3.14	4.6	7.6	249.89	3100.00		2.9	4.2	7.5	212.77	4000.00	3.1	4.4	7.8	316.47	8000.00
3.15	4.6	7.6	250.30	3200.00		2.9	4.2	7.5	212.77	4020.00	3.1	4.4	7.8	318.54	8100.00
3.16	4.6	7.6	250.71	3300.00		2.9	4.2	7.5	212.77	4040.00	3.1	4.4	7.8	320.61	8200.00
3.17	4.6	7.6	251.12	3400.00		2.9	4.2	7.5	212.77	4060.00	3.1	4.4	7.8	322.68	8300.00
3.18	4.6	7.6	251.53	3500.00		2.9	4.2	7.5	212.77	4080.00	3.1	4.4	7.8	324.75	8400.00
3.19	4.6	7.6	251.94	3600.00		2.9	4.2	7.5	212.77	4100.00	3.1	4.4	7.8	326.82	8500.00
3.20	4.6	7.6	252.35	3700.00		2.9	4.2	7.5	212.77	4120.00	3.1	4.4	7.8	328.89	8600.00
3.21	4.6	7.6	252.76	3800.00		2.9	4.2	7.5	212.77	4140.00	3.1	4.4	7.8	330.96	8700.00
3.22	4.6	7.6	253.17	3900.00		2.9	4.2	7.5	212.77	4160.00	3.1	4.4	7.8	333.03	8800.00
3.23	4.6	7.6	253.58	4000.00		2.9	4.2	7.5	212.77	4180.00	3.1	4.4	7.8	335.10	8900.00
3.24	4.6	7.6	253.99	4100.00		2.9	4.2	7.5	212.77	4200.00	3.1	4.4	7.8	337.17	9000.00
3.25	4.6	7.6	254.40	4200.00		2.9	4.2	7.5	212.77	4220.00	3.1	4.4	7.8	339.24	9100.00
3.26	4.6	7.6	254.81	4300.00		2.9	4.2	7.5	212.77	4240.00	3.1	4.4	7.8	341.31	9200.00
3.27	4.6	7.6	255.22	4400.00		2.9	4.2	7.5	212.77	4260.00	3.1	4.4	7.8	343.38	9300.00
3.28	4.6	7.6	255.63	4500.00		2.9	4.2	7.5	212.77	4280.00	3.1	4.4	7.8	345.45	9400.00
3.29	4.6	7.6	256.04	4600.00		2.9	4.2	7.5	212.77	4300.00	3.1	4.4	7.8	347.52	9500.00
3.30	4.6	7.6	256.45	4700.00		2.9	4.2	7.5	212.77	4320.00	3.1	4.4	7.8	349.59	9600.00
3.31	4.6	7.6	256.86	4800.00		2.9	4.2	7.5	212.77	4340.00	3.1	4.4	7.8	351.66	9700.00
3.32	4.6	7.6	257.27	4900.00		2.9	4.2	7.5	212.77	4360.00	3.1	4.4	7.8	353.73	9800.00
3.33	4.6	7.6	257.68	5000.00		2.9	4.2	7.5	212.77	4380.00	3.1	4.4	7.8	355.80	9900.00
3.34	4.6	7.6	258.09	5100.00		2.9	4.2	7.5	212.77	4400.00	3.1	4.4	7.8	357.87	10000.00

TABLE 3. OBLIQUE-IONOGRAM OUTPUT DATA

6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH											
PATH LENGTH	8045.35 KM	TX LAT	19.50 0FG	T <sup>0</sup> LONG -134.95 0EG	BB BEARING	Q <sub>1</sub> -Q <sub>2</sub> -Q <sub>3</sub>					
						MODE					
							FREQ	800A	800B	800C	800D
.E	.E	.E	.E				4.00	1.18	8039.09	00.10	06.20 649.50
.F2	.E	.E	.F	.E	.E	.E	4.00	13.89	8041.41	27.96	08.94 090.86
.E	.E	.E	.E				5.00	1.22	8037.90	27.09	07.49 48.28
.E	.E	.E	.F				6.00	8.28	8036.66	27.09	-8.69 90.56
.E	.E	.E	.E				7.00	1.35	8035.48	27.09	09.89 219.86
.F2	.E	.E	.E	.E	.E	.E	7.00	12.90	8026.50	27.84	018.85 275.98
.F	.E	.E	.E				8.00	1.44	8034.58	28.09	010.78 163.98
.E	.E	.E	.E				9.00	1.54	8034.34	27.13	-11.01 129.56
.E	.E	.E	.E				10.00	1.68	8035.43	27.12	03.92 104.38
.F2	.F2	.F2	.F2	.F2	.F2	.F2	10.00	23.19	8015.76	30.17	-29.59 46.37
.E	.E	.E	.E				11.00	1.85	8039.26	27.16	-6.09 88.46
.F2	.F1	.F1	.F1	.F1	.F1		11.00	13.20	7989.22	28.10	-0.13 67.34
.F2	.F2	.F2	.F2	.F2	.F2	.F2	11.00	21.70	6024.19	29.87	-21.17 47.77
.F2	.F2	.F2	.F2	.F2	.F2	.F2	11.00	24.17	8041.84	30.53	-3.51 87.41
.F1	.E	.E	.E	.E	.E		12.00	7.03	8043.03	27.63	-2.32 71.98
.F2	.F2	.F2	.F2	.F2	.F2		12.00	18.43	8021.89	29.73	-23.46 47.56
.F2	.F2	.F2	.F2	.F2	.F2		12.00	20.90	8046.18	29.80	-5.17 57.14
.F2	.F2	.F2	.F2	.F2	.F2	.F2	12.00	23.91	8042.93	30.49	-2.60 51.30
.F2	.F2	.F2	.F2	.F2	.F2		13.00	15.03	8042.09	28.03	-3.28 39.52
.F2	.F2	.F2	.F2	.F2	.F2		13.00	17.66	8031.37	29.15	-13.39 46.36
.F2	.F2	.F2	.F2	.F2	.F2		13.00	20.65	8042.79	29.77	-2.05 43.22
.F2	.F2	.F2	.F2	.F2	.F2		13.00	24.35	8037.02	30.59	-8.33 43.13
.F2	.F2	.F2	.F2	.F2	.F2		14.00	14.17	8036.79	28.60	-6.36 35.63
.F2	.F2	.F2	.F2	.F2	.F2		14.00	17.32	8037.78	28.13	-7.37 36.79
.F2	.F2	.F2	.F2	.F2	.F2		14.00	20.86	8040.51	29.87	3.16 37.01
.F2	.F2	.F2	.F2	.F2	.F2		15.00	10.72	8018.50	28.16	-24.69 29.88
.F2	.F2	.F2	.F2	.F2	.F2		15.00	13.72	8033.83	28.57	-11.72 31.79
.F2	.F2	.F2	.F2	.F2	.F2		15.00	17.35	8042.26	29.18	-3.09 32.03
.F2	.F2	.F2	.F2	.F2	.F2		15.00	22.10	8045.07	30.17	-0.29 30.40
.F2	.F2	.F2	.F2	.F2			16.00	10.03	8044.89	28.26	-0.66 27.36
.F2	.F2	.F2	.F2	.F2			16.00	13.52	8036.26	28.36	-0.67 24.27
.F2	.F2	.F2	.F2	.F2			16.00	17.62	6067.40	29.33	2.13 27.63
.F2	.F2	.F2	.F2	.F2			17.00	6.29	8026.07	27.85	-19.33 62.97
.F2	.F2	.F2					17.00	9.66	8046.63	28.17	-0.72 24.79
.F2	.F2	.F2					17.00	13.56	8043.77	28.63	-1.39 25.01
.F2	.F2						18.00	0.26	8052.64	27.70	10.29 14.68
.F2	.F2						18.00	5.64	8046.42	27.92	1.07 27.88
.F2	.F2						18.00	9.49	8042.59	28.17	-2.76 27.35
.F2	.F2						18.00	13.91	8040.59	28.69	-6.76 21.95
.F2	.F2						19.00	5.28	8040.53	27.86	-4.82 19.12
.F2	.F2						19.00	9.51	8042.76	28.18	-0.59 20.05
.F2	.F2						19.00	15.25	8033.20	28.90	-12.15 18.64
.F2	.F2						20.00	5.08	8042.24	27.86	-3.11 17.45
.F2	.F2						20.00	9.73	8042.64	28.22	-2.71 17.89
.F2	.F2						21.00	5.02	8044.62	27.86	-0.73 15.90
.F2	.F2						21.00	10.22	8045.00	28.32	-0.35 15.80
.F2	.F2						22.00	5.09	8042.56	27.86	-2.79 14.45
.F2	.F2						23.00	5.29	8037.81	27.86	-7.54 13.09
.F2	.F2						24.00	5.68	8040.43	27.93	-4.92 11.79
.F2	.F2						25.00	6.71	R010.11	27.91	-29.24 80.27

TABLE 4. RAY-PATH OUTPUT DATA

6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH						6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH					
PATH LENGTH	3045.35 KM	TX LAT	19.50 DEG	TX LONG	-156.95 DEG	TX BEARING	50.26 DEG	TX LENGTH	8045.35 KM	TX LAT	19.50 DEG
NODE	.F1 .E .E					MODE	.F2 .F2 .F2 .F2				
12.000 MC		7.0005 DEGREES						12.000 MC	1A.426 NEGATIVES		
HEIGHT	RANGE					HEIGHT	RANGE				
140.00	755.85					140.00	377.77				
107.17	1092.09					169.34	460.10				
100.00	1928.36					150.00	558.19				
0.	2512.50					100.00	662.74				
412.74	3228.44					0.	960.20				
0.	3944.77					100.00	1353.26				
110.83	4635.49					149.43	1599.69				
0.	5326.21					150.00	1822.36				
110.00	4906.97					100.00	1966.47				
0.	4687.74					0.	2201.93				
109.73	7365.38					140.00	2638.69				
0.	8043.03					179.94	2893.49				
						150.00	3124.21				
						100.00	3269.73				
						0.	3547.19				
						149.00	3947.12				
						174.68	4222.29				
						150.00	4478.56				
						100.00	4621.89				
						0.	4899.35				
						140.00	5201.74				
						193.95	5655.36				
						150.00	5987.47				
						100.00	6137.81				
						0.	6415.27				
						140.00	6818.16				
						204.79	7218.02				
						150.00	7593.56				
						100.00	7746.43				
						0.	8021.89				

6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH			6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH		
PATH LENGTH	8045.35 KM	TX LAT 19.59 OEG	PATH LENGTH	8045.35 KM	TX LAT 19.50 OEG
MODE *F2	*F2	*F2	MODE *F2	*F2	*F2
12.000 MC	20.906 DEGREES		12.000 MC	23.913 DEGREES	
HEIGHT	RANGE		HEIGHT	RANGE	
140.00	335.66		140.00	293.76	
170.63	437.73		173.20	398.68	
150.00	517.86		150.00	484.11	
100.00	630.00		100.00	583.39	
0.	815.45		0.	797.36	
140.00	1221.78		140.00	1091.12	
132.09	1437.13		195.22	1264.51	
150.00	1630.90		150.00	1458.78	
100.00	1755.06		100.00	1566.10	
0.	2000.51		0.	1780.07	
140.00	2349.05		140.00	2022.37	
985.51	2566.21		192.95	2260.54	
150.00	2761.59		150.00	2459.57	
160.00	2887.79		100.00	2568.11	
0.	3133.23		0.	2792.07	
140.00	3483.69		140.00	3005.53	
172.86	3687.7C		162.26	3210.43	
150.00	3869.37		150.00	3435.86	
100.00	3997.29		100.00	3555.43	
0.	4262.68		0.	3759.39	
140.00	4594.63		140.00	4683.79	
182.54	4633.54		161.43	4293.98	
150.00	5050.80		150.00	4427.74	
100.00	5179.98		100.00	4955.11	
0.	5425.43		0.	4749.08	
140.00	5778.50		140.00	5054.26	
203.42	6074.56		193.36	5272.78	
150.00	6369.59		150.00	5472.17	
100.00	6679.62		100.00	5983.17	
0.	6925.06		0.	5707.13	
940.00	7078.75		140.00	6102.78	
205.60	7382.56		210.32	6361.74	
850.00	7664.24		150.00	6601.58	
100.00	7794.74		100.00	6792.95	
0.	8040.16		0.	6926.92	

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\* 13b \*

• OCTOBER 1962 1737.36 GMT PAHOA/BEAUFORD PATH

PATH LENGTH	8045.35 KM	TX LAT	19.50 DEC	TX LONG -154.95 DEC	RX BEARING	90.24 DEC	PATH LENGTH	8045.35 KM	TX LAT	19.50 DEC	TX LONG -154.95 DEC	RX BEARING	90.24 DEC
MODE	F2	•F2	•F2	•F2	•F2	•F2	MODE	•F2	•F2	•F2	•F2	•F2	•F2
18.000 MC	6.285 DEGREES						17.000 MC	9.059 DEGREES					
HEIGHT	RANGE						HEIGHT	RANGE					
140.00	795.34						160.00	625.52					
180.09	1164.93						182.75	825.41					
150.00	1494.02						190.00	989.93					
100.00	1755.57						100.00	1199.92					
0.	2376.09						0.	1674.83					
140.00	3229.29						140.00	2328.72					
169.62	3636.69						165.03	2663.34					
650.00	4001.77						150.00	2961.70					
400.00	4285.17						100.00	3181.45					
0.	4905.69						0.	3650.36					
140.00	5777.34						140.00	4318.01					
208.33	6457.01						181.34	4680.38					
150.00	7109.07						150.00	5007.72					
00.00	7405.51						100.00	5232.91					
0.	8026.02						0.	5707.42					

• OCTOBER 1962 1737.36 GMT PAHOA/BEAUFORD PATH

HEIGHT	RANGE	HEIGHT	RANGE	HEIGHT	RANGE								
140.00	795.34	160.00	625.52	182.75	825.41	190.00	989.93	100.00	1199.92	1674.83	2328.72	165.03	2663.34
180.09	1164.93	180.00	1199.92	0.	1674.83	140.00	2328.72	160.00	2961.70	100.00	3181.45	0.	3650.36
150.00	1494.02	150.00	989.93	100.00	1199.92	160.00	2663.34	140.00	4318.01	181.34	4680.38	150.00	5007.72
100.00	1755.57	100.00	1199.92	0.	1674.83	140.00	2328.72	160.00	2961.70	100.00	3181.45	0.	3650.36
0.	2376.09	0.	1674.83	0.	1674.83	0.	1674.83	0.	1674.83	0.	1674.83	0.	1674.83
140.00	3229.29	140.00	4318.01	181.34	4680.38	150.00	5007.72	100.00	5232.91	160.00	5707.42	150.00	625.52
169.62	3636.69	169.62	5707.42	0.	5707.42	140.00	625.52	0.	625.52	0.	625.52	0.	625.52
650.00	4001.77	650.00	5232.91	100.00	5232.91	160.00	5707.42	100.00	5707.42	100.00	5707.42	100.00	625.52
400.00	4285.17	400.00	625.52	0.	625.52	0.	625.52	0.	625.52	0.	625.52	0.	625.52
0.	4905.69	0.	625.52	0.	625.52	0.	625.52	0.	625.52	0.	625.52	0.	625.52

6 OCTOBER 1962 1737.36 GMT PAMPA/BEFORO PATH  
 PATH LENGTH 8045.35 °E Tx LAT 19.50° S ECG  
 NOOE -F2 -F2 -F2 -F2 -F2 -F2  
 17.000 MC 13.565 DEGREES  
 WEIGHT RANGE  
 145.00 490.10  
 181.00 578.10  
 150.00 636.21  
 100.00 1003.83  
 0. 1368.75  
 140.00 1873.05  
 197.43 2178.60  
 150.00 2455.21  
 100.00 2628.44  
 0. 2991.34  
 140.00 3498.91  
 178.86 3763.34  
 150.00 3997.72  
 100.00 4171.58  
 0. 4536.50  
 140.00 5046.28  
 198.22 5386.85  
 150.00 5686.20  
 100.00 5861.46  
 0. 6226.73  
 140.00 6777.86  
 217.70 7155.07  
 150.00 7522.65  
 100.00 7678.85  
 0. 8043.77

## V. THE KIFT-FOOKS RAY TRACING PROGRAM

The ionospheric ray-tracing program described here is essentially the same as that described by G. F. Fooks in his report [Ref. 12]. The same equations are used and the same basic procedure is followed; however, certain modifications and additions to the program have been made to allow the calculations of reflection heights from the ionospheric layers, and to allow the calculation of an approximate value for ray attenuation due to D-layer absorption along the path.

### A. PHYSICAL ASSUMPTIONS

The program uses a curved-earth, curved-ionosphere geometry, and the ionosphere is assumed to consist of a number of curved layers, each with a parabolic electron-density distribution. The ionospheric layers considered are E,  $F_1$  and  $F_2$ . A sporadic E layer ( $E_s$ ) may also be included in the calculations; however, when it is, it is treated not as a parabolic layer, but rather as a thin, specularly reflecting sheet. The earth's magnetic field and layer tilts are ignored.

Figure 3 illustrates the geometry of the ionospheric layer structure.

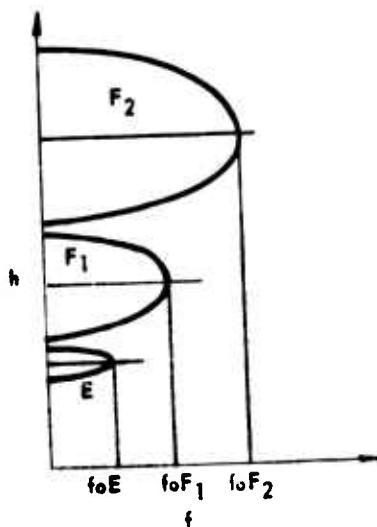


FIG. 3. IONOSPHERIC-LAYER STRUCTURE (PARABOLIC).

## B. GENERATION OF THE IONOSPHERE

Figure 4 illustrates the geometric parameters for an arbitrary parabolic layer.

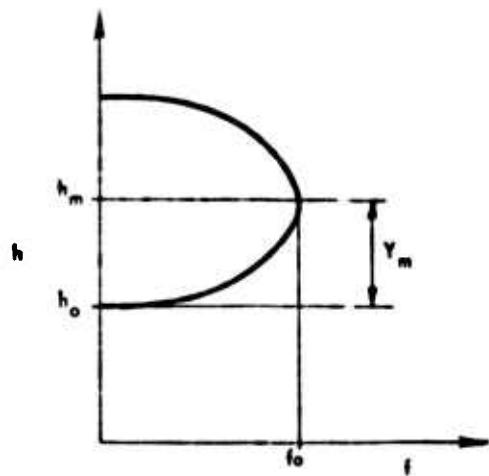


FIG. 4. GEOMETRIC PARAMETERS FOR AN ARBITRARY PARABOLIC LAYER.

Since the behavior of the E and F<sub>1</sub> layers is well understood, these layers are generated by several analytic expressions, which take into consideration the sunspot number and the solar zenith angle.

For the E layer we have:

$$\left. \begin{aligned} f_{\text{o}}^{\text{E}} &= 3.4 (1.0 + 0.0097 \cdot \text{SSN})^{0.27} \cdot \cos^{0.33} \chi \\ f_{\text{o}}^{\text{E}} &= 0.0 \\ h_m^{\text{E}} &= 120.0 \text{ km} \\ y_m^{\text{E}} &= 20.0 \text{ km}, \end{aligned} \right\} \quad \begin{aligned} \chi &\leq 70^\circ \\ \chi &\leq 70^\circ \end{aligned} \quad (1)$$

where:

$f_{\text{o}}$  = critical frequency for the layer in megacycles  
 $\circ$  (vertical incidence)

SSN = sunspot number

$\chi$  = solar zenith angle.

For the  $F_1$  layer:

$$\left. \begin{array}{l} f_o F_1 = 1.4(f_o E) \\ h_m F_1 = 210.0 \text{ km} \\ y_m F_1 = 60.0 \text{ km} \end{array} \right\} \quad (2)$$

For the  $F_2$  layer, values of  $f_o F_2$  and  $h_m F_2$  are supplied to the program either as predicted values or observed values at arbitrary points along the path, and the program constructs a parabolic  $F_2$  layer under the assumption:

$$y_m F_2 = 0.4 h_o F_2, \quad (3)$$

where  $y_m = h_m - h_o$

Values of  $f_o E_s$ , if they are different from zero, are supplied to the program in terms of their position on the path. The height of the  $E_s$  layer is assumed constant at 100.0 km.

An equation for  $\cos \chi$  using the path geometry is presented in Appendix B.

In Appendix C a method is given for obtaining values of  $h_m F_2$  using predicted values of  $f_o F_2$  and  $F_2$  4000 MUF. These are the two parameters obtained from the CRPL ionospheric predictions.

### C. EQUATIONS FOR RAY-PATH CALCULATIONS

Below the ionosphere and between ionospheric layers the ray is assumed to travel in a straight line.

The  $E_s$  layer either specularly reflects the ray or allows it to pass undeviated. For the parabolic layers the following equations apply:

$$\Delta P' = \frac{2f}{f_o} y_m \cdot \operatorname{argtanh} \left( \frac{f}{f_o} \cos i \right) \quad (4)$$

If the ray is reflected by the layer, and

$$\Delta P' = \frac{2f}{f_o} y_m \operatorname{argcoth} \left( \frac{f}{f_o} \cos i \right) \quad (5)$$

If the layer transmits the ray, but causes bending, where:

$\Delta P'$  = virtual path in the layer

$f$  = wave frequency

$f_o$  = layer critical frequency

$i$  = angle between the ray, extrapolated along a straight line to the level of maximum electron density, and the vertical at that level (as illustrated in Fig. 5).

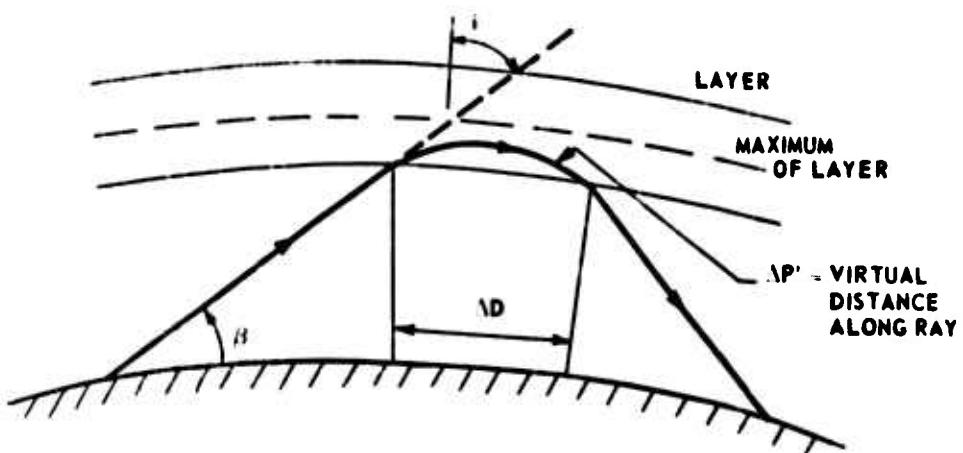


FIG. 5. OBLIQUE-INCIDENCE RAY-PATH GEOMETRY.

For transmission through a layer or for reflection from the bottom of a layer,

$$\Delta D = \frac{R}{R + h_m} \sin i \Delta P'. \quad (6)$$

If the ray is reflected from the top of a layer,

$$\Delta D = \frac{R}{R - h_m} \sin i \Delta P', \quad (7)$$

where  $\Delta D$  is the range along the path covered while the ray is in the layer, and  $R$  is the earth's radius.

In the course of the ray tracing, as the ray enters a layer, there are three possible consequences:

1. The ray is reflected from the layer.
2. The ray is transmitted through the layer and deviated.
3. The ray is transmitted through the layer undeviated (straight-line transmission).

Let

$$K = (f/f_o) \cdot \cos i.$$

Then if

$K < 1$	the ray is reflected	}
$K = 1$ $P' = \infty$ ,	the next ray is taken	
$1 < K < 2$	the ray is transmitted and deviated	
$K \geq 2$	the ray is transmitted and undeviated	

(8)

The equations used for undeviated transmission through a layer, between layers, and from the ground to the bottom of the ionosphere are:

$$\sin i_2 = \frac{(R + h_1) \sin i_1}{(R + h_2)} \quad (9)$$

$$\Delta P' = \frac{(R + h_2) \sin (i_1 - i_2)}{\sin i_1} \quad (10)$$

$$\Delta D = R(i_1 - i_2) \quad (11)$$

for straight-line transmission between two points at heights  $h_1$  and  $h_2$  with associated vertical angles  $i_1$  and  $i_2$ .

During the course of the ray-tracing procedure, two layers may happen to overlap (most likely the F1 and F2 layers). When this occurs, the ray is extrapolated back along a straight-line path, tangential to its direction when it emerges from the first layer, to its point of entry to the second layer, (Fig. 6).

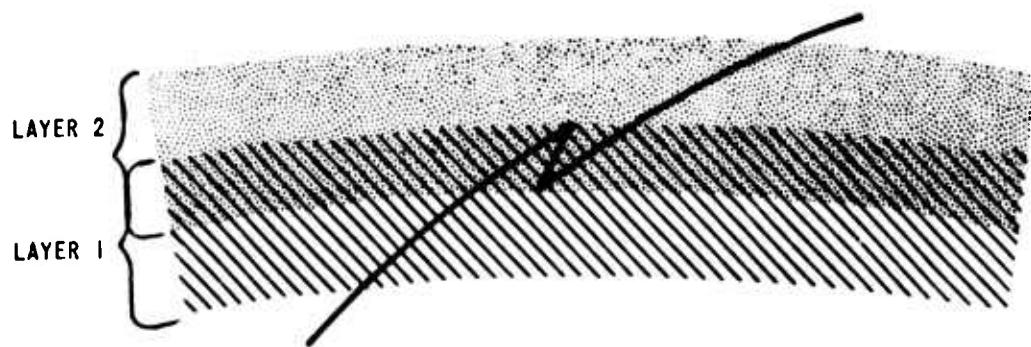


FIG. 6. OVERLAPPING-LAYER PROCEDURE

## VI. STANFORD VERSION OF KIFT-FOOKS RAY-TRACING PROGRAM

### A. BASIC COMPUTATIONAL PROCEDURE

Figure 7 is a logical flow diagram of the computational procedure; it is not intended as a detailed flow chart of the program, but merely as a gross logical description of the computational process.

The input data to the program are the path length between the receiver and the transmitter, the coordinates of the transmitter, the true bearing of the receiver from the transmitter, sunspot number, sun declination, apparent solar time at Greenwich;  $F_2$ -layer data in the form of either  $f_o F_2$  and  $h_m F_2$  or  $f_o F_2$  and  $F_2$  4000 MUF;  $E_s$  data, if any, plus a range of frequencies and a range of take-off angles to be investigated for the given ionosphere, and a set of frequencies for which ray-reflection-height information is desired.  $F_2$  and  $E_s$  data are described in terms of their range along the path from the transmitter.

Once the data for the path have been read by the program, a table of ionospheric data is produced for use by the program. Equations (1) and (2) are evaluated at 100-km intervals along the path. A second-degree polynomial is fitted to successive triplets of  $f_o F_2$  and  $h_m F_2$  data points and these polynomials are evaluated at 100-km intervals along the path. Tables of  $E_s$ , if required, are compiled at 10-km intervals within each  $E_s$  patch considered. When, during ray tracing, values within the ionospheric tables are required between the calculated 100-km (10-km for  $E_s$ ) points, linear interpolation is used.

After the generation of the ionospheric tables, the values of the critical frequency,  $f_o$  and height vs range for each layer are printed out (Table 2) and the actual ray-tracing process begins.

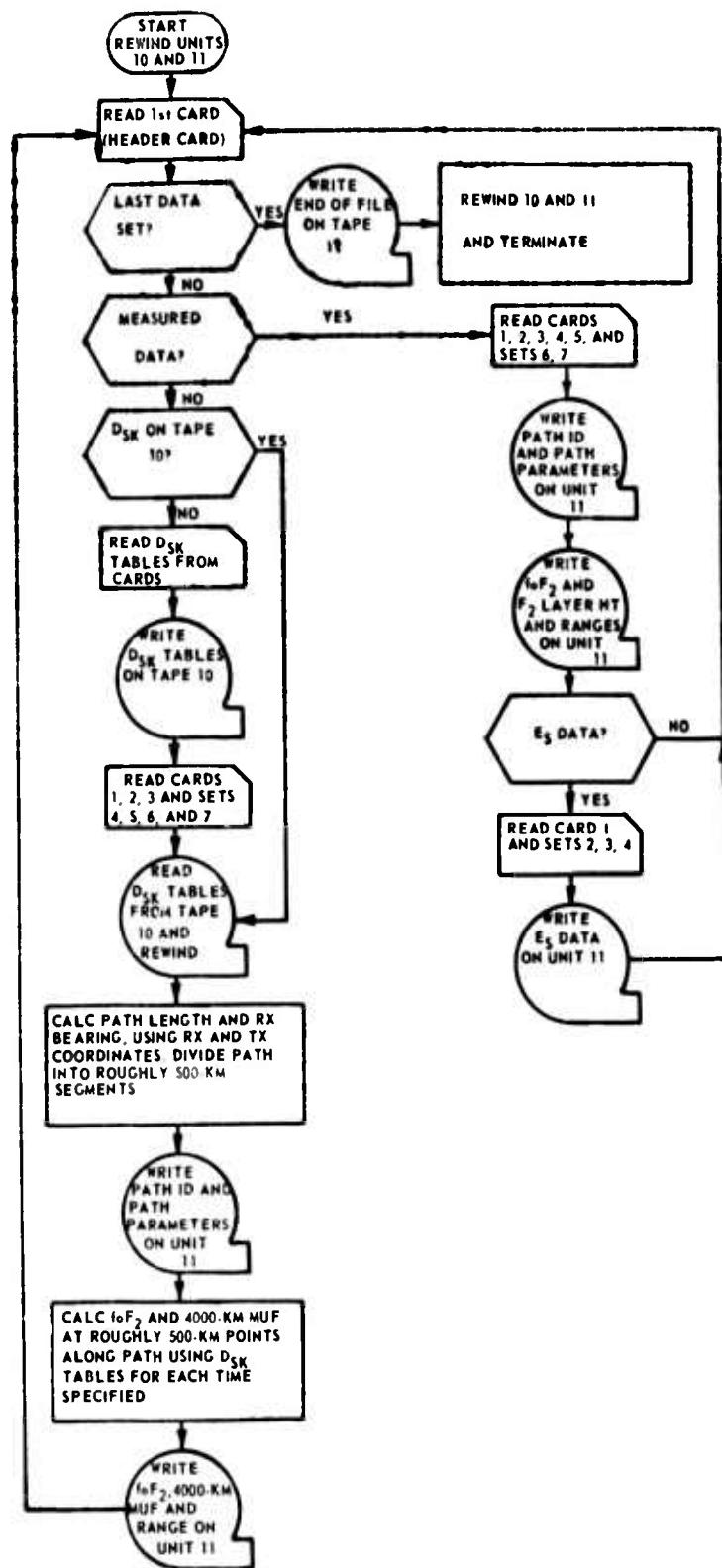


FIG. 7A DATA PROGRAM OF RAY-TRACE PROGRAM.

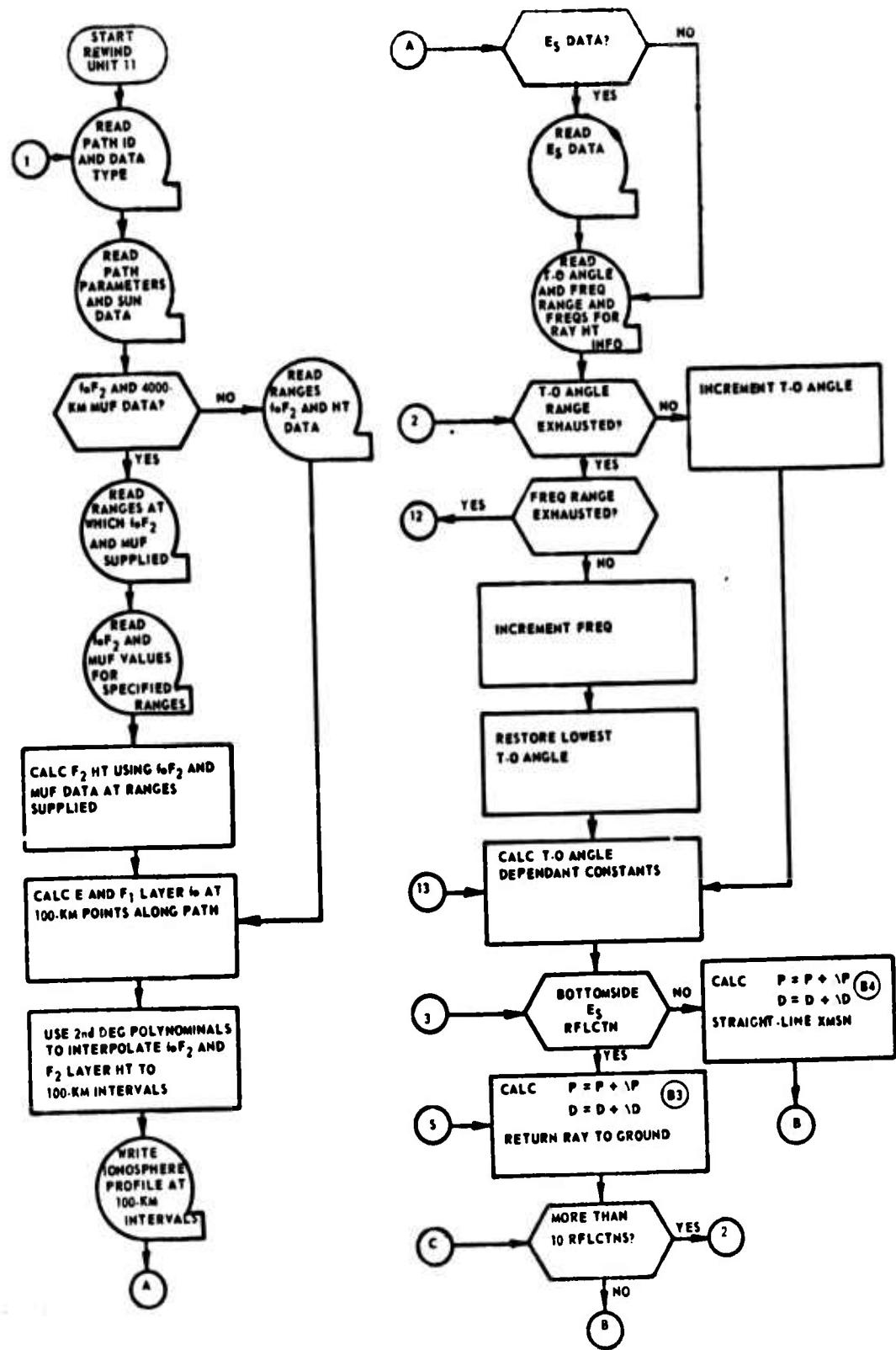
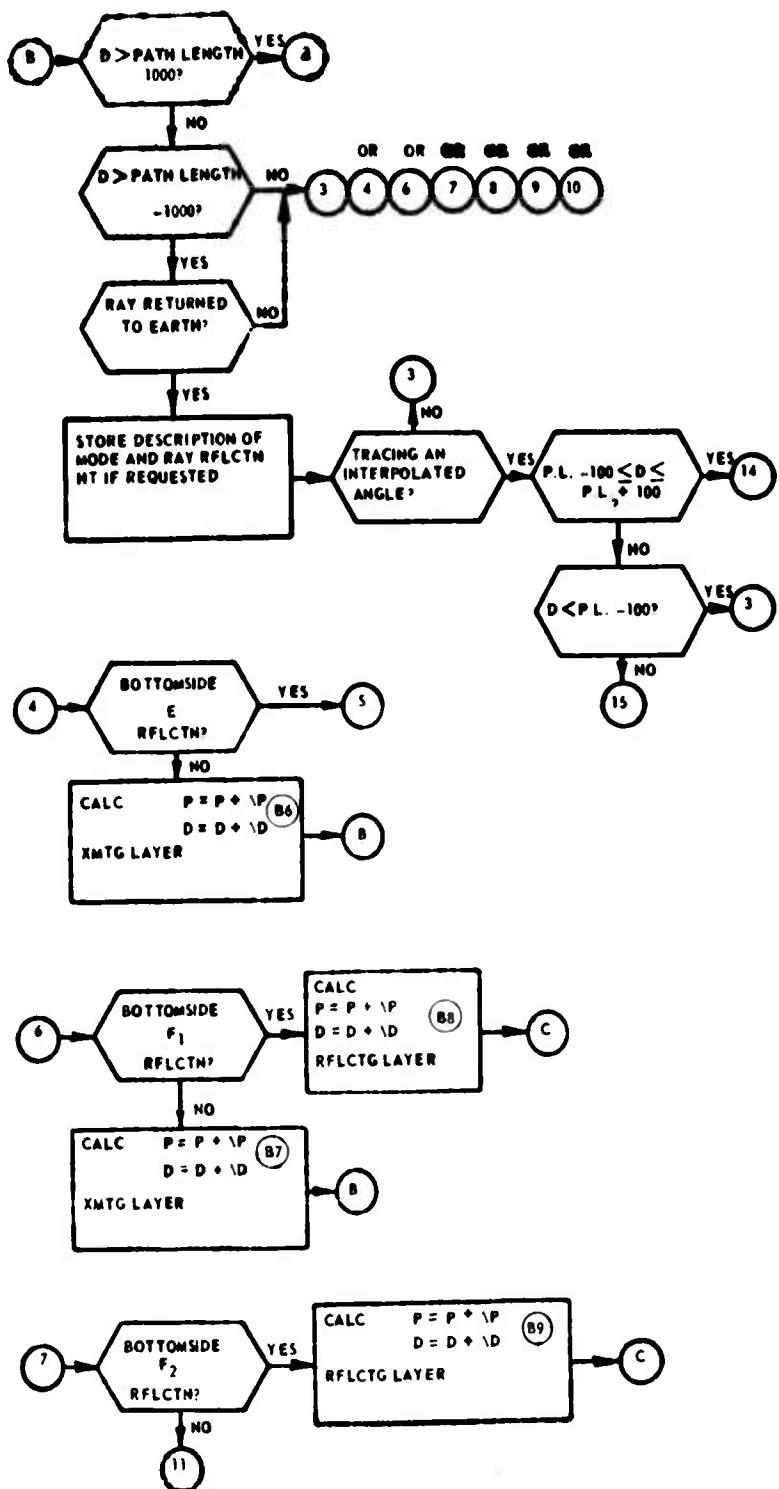
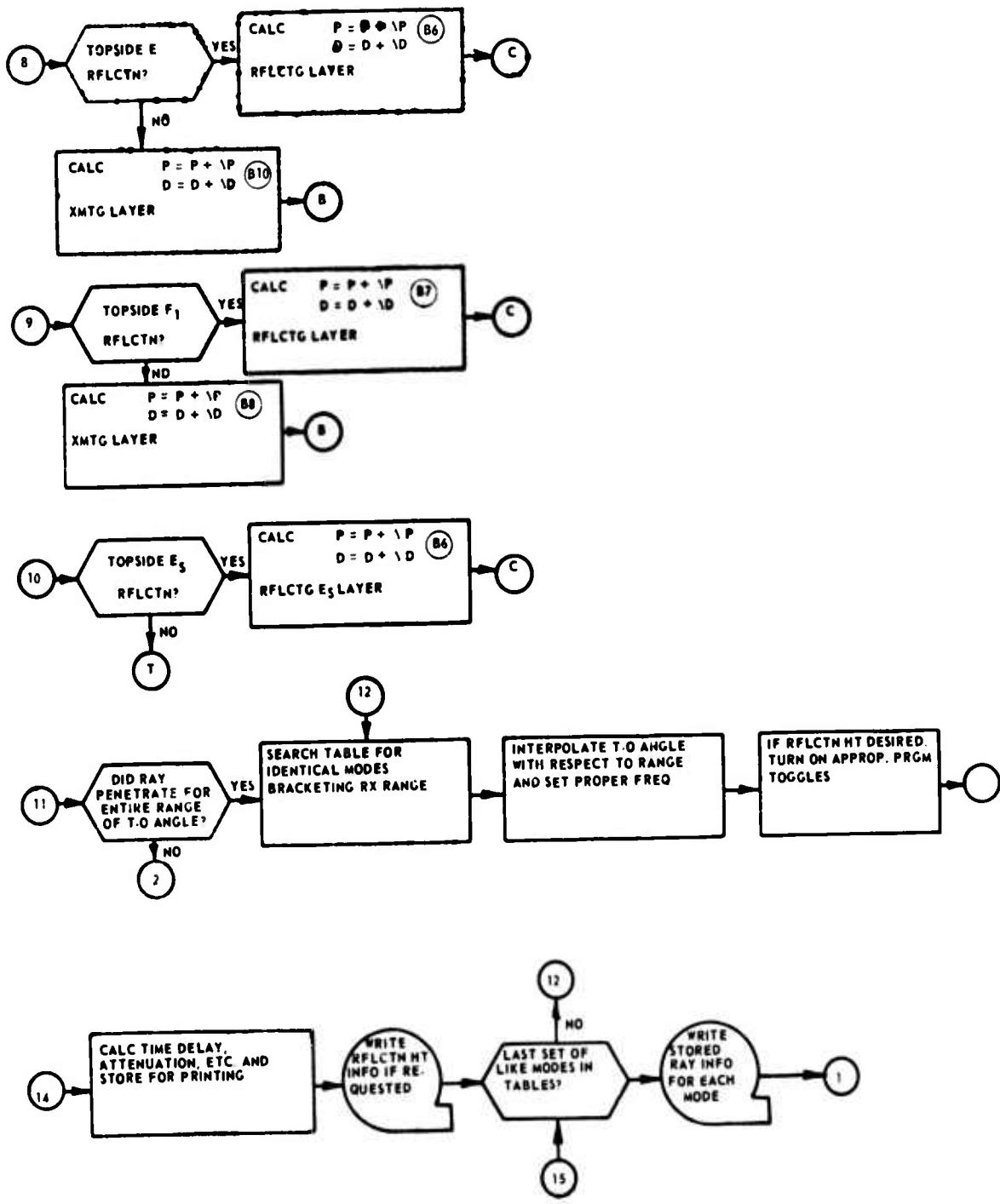


FIG. 7B FLOW DIAGRAM OF RAY-TRACE PROGRAM.





For each frequency of the specified frequency range, rays are traced from the transmitter for all take-off angles of the specified take-off angle range. A ray is traced until it falls within  $\pm 1000$  km of the receiver, each reflection from a layer being recorded, in coded form, in a "reflection index". A maximum of ten reflections per ray is allowed. When a ray falls beyond the receiver range  $\pm 1000$  km, tracing of that ray is terminated, the reflection index and accumulated values of  $P'$  and  $D$  are restored to zero and the next ray of the series is traced. When the ray falls within  $\pm 1000$  km of the receiver range its reflection index is stored in a table, along with  $P'$  and  $D$  for that particular ray, and the next ray of the series is traced.

Once all rays for a given frequency have been traced, the table of reflection indices is searched for rays of like modes, a linear interpolation of take-off angle with respect to the actual range of the ray and the range of the receiver is performed, and a new ray with the interpolated take-off angle is traced. At this time the height of the ray at its reflection points is calculated in addition to an estimate of D-layer attenuation. (These equations appear in Appendices D and E, respectively.) If this new ray does not fall within  $\pm 100$  km of the receiver, it is ignored and the next pair of like rays (if any) is considered. If it falls within  $\pm 100$  km of the receiver, its delay time is calculated from

$$\text{Delay time (ms)} = \frac{P' - (\text{Receiver Range} - D)}{300.0} \quad (12)$$

and the final results are printed. The next pair of like rays (if any) in the table is then considered.

The printed output (Table 3) for each mode consists of the path parameters, the reflections that take place for the mode in "decoded" form, the frequency, take-off angle, ground range, and delay time for the mode. A list of heights

vs range for the reflection points on the path is printed if this information is requested of the program (Table 4).

This process continues for each frequency in the specified range until the frequency range is exhausted or until some frequency in the range fails to propagate any rays between the transmitter and receiver. At this point new ionospheric and/or new path data may be read into the program and the process may be repeated.

#### B. PROGRAM DETAILS

The ray-tracing program is written in the FORTRAN II computer language, specifically for an IBM 7090 data-processing system. With modifications to the input/output statements, the program could probably be adapted, with little trouble, to other systems such as the IBM 709, CDC 1604, etc. The program requires two magnetic-tape units, one designated logical unit 11 and the other designated as logical 6. The tape on logical unit 11 serves as an input tape and the tape on logical unit 6 is the output tape.

Data for the ray-tracing program are prepared by a second program, which shall be referred to as the "data program". The data program requires, as its input, tables of  $f_0 F_2$  and M 3000 factor coefficients for the month for which ray tracing is to be done, in addition to parameters associated with the paths which are to be ray-traced. The output of the data program is a magnetic tape that is used as the input tape for the ray-tracing program.

The tables of  $f_0 F_2$  and M 3000 factor coefficients (Dsk) may be obtained in punched-card form from the Bureau of Standards CRPL at Boulder, Colorado. (See CRPL Ionospheric Predictions, Handbook 90. [Ref. 18]) These tables also contain the sunspot number for the month.

The data program will also accept as input, actual measured values of  $f_0F_2$ - and  $F_2$ -layer real height as a function of their position on the path, to be used by the ray-tracing program.

Appendix F contains listings of the FORTRAN source programs for both the data and ray-tracing programs in addition to sample output from the ray-tracing program which has already appeared as Tables 2,3, and 4, and sample input for the data program.

### C. OPTIONS AVAILABLE ON THE DATA PROGRAM

In preparing data for paths to be ray traced for a given month, the tables (on cards) of  $D_{sk}$  need be read only once by the program. When the program reads the  $D_{sk}$  tables from cards it places them on magnetic tape (logical unit 10), in binary form, where they are available for future use.

Normally, ray tracing is done over a given path, for a 24-hour period, once each hour; however, provisions have been made in the data program to allow tracing for an arbitrary number of selected times (at most 100) on any given path. The number of times to be traced is specified to the program, followed by the actual times to be used. For example, in the normal case 24 times would be specified followed by each hour from 0 through 23.

When empirical data are to be used for ray tracing a given path, that is, ionosonde records of  $f_0F_2$ - and  $F_2$ -layer real heights, even though the CRPL tables of  $D_{sk}$  are not used, the  $D_{sk}$  tape must be mounted on unit 10 nonetheless. These empirical data are presented to the data program in the form of  $f_0F_2$ - and  $F_2$ -layer height as a function of distance along the great-circle path, measured in kilometers from the transmitter. There must be an odd number of measurement points specified.

Sporadic-E data may also be included when the empirical data form is used. No provisions have been made to include sporadic-E when the prediction tables are used. However, this omission may be remedied with only minor difficulty; and procedure will be discussed after a description of the output from the ray-tracing program.

The data program writes a BCD tape on unit 11 which is used as an input tape by the ray-tracing program.

#### D. INPUT TO AND OUTPUT FROM THE RAY-TRACING PROGRAM

Input to the ray-tracing program is provided by a binary-coded decimal (BCD) tape written by the data program. It is to be mounted on unit 11. Output from the ray-tracing program consists of an ionospheric profile (Table 2), constructed from either the CRPL predictions or empirical data, at 100-km intervals along the path; path identification information such as the name or number of the path, the time, month and day for which the tracing is being done, etc. The actual path-identification information used is up to the user and will be explained in the section on the preparation of input cards for the data program.

The length of the great-circle path between the transmitter and receiver, the latitude and longitude of the transmitter (Tx), the bearing from the transmitter to the receiver are all printed and labeled for each time a series of rays is traced. (In the normal case, once each hour for the 24-hour period.)

Actual information concerning the rays traced appears in Table 3 under the following column headings, with the associated definitions:

MODE: The mode structure of the ray propagated between the transmitter and receiver. The symbol ".E" indicates a ray reflection from the bottom side of the E layer. The symbol "-E" indicates a ray

reflection from the top side of the E layer. The same definitions apply to Es, F<sub>1</sub>, and F<sub>2</sub> layers. Obviously, "-F<sub>2</sub>" is not defined and will not occur.

FREQ: The frequency (in megacycles) of the ray traced.

BETA: The take-off angle (in degrees) of the ray traced.

DIST: The actual ground distance (in kilometers) the ray travels between transmitter and receiver. Because of inaccuracies in the ray-tracing technique this distance will, in general, not be equal to the actual path length.

TIME: The delay time (in milliseconds) of the ray traced, corrected to the actual path length.

DIFF: The difference (in kilometers) between the ground distance the ray travels and the actual path length.

DB: The attenuation, (in decibels) the ray experiences due to D layer absorption only.

Information concerning reflection heights of the rays is also printed (Table 4), but only if it is specifically requested of the program. The details for obtaining this information are discussed in the next section.

If the reflection-height information is requested it appears in the following form: the path parameters and identification are printed, the MODE is specified (as above), along with the ray frequency and take-off angle. The heights appear under a column headed HEIGHT and the corresponding range appears under a column headed RANGE; both are in kilometers.

In all cases an ionospheric profile along the path is printed prior to the printing of any other information. It consists of the path-identification information and columns headed FOE, FOF1, FOF2, HT FOF2 and RANGE. The  $f_o$  values are in megacycles and the  $f_o F_2$  height column is in kilometers, as are the ranges. The range is measured from the transmitter end of the path, and the values fall on the great circle between the transmitter and receiver. The path parameters printed consist of the PATH LENGTH, TX LAT (transmitter latitude), TX LONG (transmitter longitude),

and RX BEARING (the great-circle bearing from the transmitter to the receiver).

In order to provide sporadic-E information on ray tracings that make use of the CRPL prediction tables, it is necessary, first, to accomplish the required tracings without  $E_s$  data, and then, using the  $F_0 F_2$ - and  $F_2$ -layer real-height information provided by the ray-tracing program, resubmit this information to the data program in the empirical-data format, along with the required  $E_s$  data. This technique was adopted in the interest of programming simplicity and, since the inclusion of  $E_s$  is usually done on an "after-the-fact" basis, it would seem a justifiable approach.

## E. INPUT-CARD FORMATS FOR THE DATA PROGRAM

### 1. First Card

The first card of every data set contains the program variables called IDATA, IDS<sub>sk</sub>, IEND, in that order. This card is read under a FORTRAN format of (3I2). The value of each of these variables may be "1" or "0" (zero).

If IDATA = 1: Data are to be supplied to the program in the empirical format.

If IDATA = 0: Data are to be supplied to the program in the form to make use of the CRPL D<sub>sk</sub> tables.

If IDS<sub>sk</sub> = 1: The D<sub>sk</sub> tables for the month in question have not yet been put on magnetic tape and immediately follow this first card.

If IDS<sub>sk</sub> = 0: The D<sub>sk</sub> tables for the month in question are on magnetic-tape unit 10.

If IEND = 1: An END OF FILE mark is to be written immediately on magnetic-tape unit 11 and program execution is to be terminated.

If IEND = 0: Additional sets of path data follow.

## 2. Cards for Program Using D<sub>sk</sub> Tables

The following cards constitute the information required to generate data for the ray-tracing program using the D<sub>sk</sub> tables:

Card #1: Contains the program variables TXLAT, TXLON, RXLAT, RXLON, SUNDEC.

TXLAT: The latitude of the transmitting point in degrees and hundredths of degrees. North latitude is +; South latitude is -. Format F7.2.

TXLON: The longitude of the transmitting point in degrees and hundredths of degrees. East longitude is +; West longitude is -. Format F8.2.

RXLAT: The latitude of the receiving point. Same as TXLAT.

RXLON: The longitude of the receiving point. Same as TXLON.

SUNDEC: The declination of the sun in degrees, Format F7.2.

This information is obtained from the Nautical Almanac.

Card #2: Contains the program variables FREQL, FREQD, FREQH, ANGLL, ANGLD, ANGLH.

FREQL: The lowest frequency to be traced, in megacycles. Format F7.3.

FREQD: The frequency increment to be used between the lowest frequency and highest frequency, in megacycles. Format F7.3.

FREQH: The highest frequency to be traced, in megacycles. Format F7.3.

ANGLL: The lowest take-off angle to be traced, in degrees. Format F7.3.

ANGLD: The take-off angle increment to be used between the lowest angle and highest angle, in degrees, Format F7.3.

ANGLH: The highest take-off angle to be traced, in degrees. Format F7.3

Card #3: Contains the program variable NTIMES.

NTIMES: The number of specific times of day to be used by the ray-tracing program for the path described. 0 < NTIMES ≤ 100. Format I3.

Card Set #4: Contains the program variable TIME (I). One card for each value of TIME (I), in GMT, to be used. The number of cards must correspond to NTIMES. Format F6.2.

Card #5: Contains the program variable NCHT. NCHT is

the number of discrete frequencies for which detailed ray-reflection-height information is desired. If no such information is desired, NCHT = 0. Format I4.  $0 \leq \text{NCHT} \leq 50$ .

Card Set #6: Contains the program variable HFREQ (I),  $I = 1, 2, \dots, \text{NCHT}$ . There are NCHT cards in this set, each containing a discrete frequency for which ray-reflection-height-information is required. If NCHT = 0 there are no cards in this set. Note - frequencies specified must correspond to frequencies specified to be traced by the program. Format F7.3.

Card Set #7: Contains alpha-numeric data in columns 1 thru 60 for identification purposes. One card must appear for each time used. The actual information used is at the user's discretion.

Additional sets of path data may follow, providing each set is prefaced by a card as described in Sec. 1.

A card of the type described in Sec. 1 with IEND = 1 should immediately follow the last set of path data.

### 3. Cards for Program Using Real-Height Measurements

The following cards constitute the information required to generate data for the ray-tracing program using actual measurements of  $f_0 F_2$ - and  $F_2$ -layer real height. Remember, it is necessary to have the  $D_{sk}$  tape mounted on unit 10, even though the  $D_{sk}$  tables are not used!

A card as described in Sec. 1 with IDATA = 1.

Card #1: Same as card #1, Sec. 1.

Card #2: Same as card #2, Sec. 1.

Card #3: Contains the program variable NSETS. NSETS:

The number of sets of empirical data, for the path described by cards #1 and #2, to be read.  $0 < \text{NSETS}$ .

Format I3.

Card #4: Same as Card #7 of Sec. 1.

Card #5: Contains the program variables NPTS, SSN, HOUR.

NPTS: The number of measurements along the path as described by cards #1 and #2.

$3 \leq \text{NPTS} \leq 100$  and must be odd. Format I3.

SSN: Sunspot number. Format F5.1.

HOUR: The time, in GMT, of the measurements. Format F6.2.

Card Set #6: Contains the program variables AFOF2(I),  
AHT(I), DIST(I). I = 1, 2, . . . NPTS.

AFOF2(I):  $f_o F_2$  in megacycles at the point I. Format F6.2.

AHT(I): Real height of the  $F_2$  layer maximum at the point I, in kilometers. Format F7.2.

DIST(I): The distance from the transmitter along the great-circle path to the point I, in kilometers. The first measurement must be at the transmitter (DIST (1) = 0) and the last measurement must be at the receiver (DIST (NPTS) = path length). Format F9.2.

Card #7: Contains the program variable IES.

If IES = 0, no  $E_s$  data are to be considered.

If IES = 1,  $E_s$  data immediately follow. Format I3.

#### 4. Cards for Program Using Sporadic E Data

Card #1: Contains the program variable NPATCH.

NPATCH: The number of sporadic E patches on the path this particular time.  $0 < \text{NPATCH} \leq 10$ . Format I4.

Card Set #2: Contains the program variables PSTART(I),  
PEND(I), I = 1, 2, . . . NPATCH.

PSTART(I): The distance from the transmitter, along the great-circle path, of the starting point of  $E_s$  patch number I.

PEND (I): The distance from the transmitter, along the great-circle path, of the ending point of  $E_s$  patch number I. Format 1X, 2F9.2.

Card #3: Contains the program variable NPT.

NPT: The number of  $f_o E_s$  values to be read in for patch number "I".  $0 < \text{NPT} \leq 10$ . Format I4.

Card Set #4: Contains the program variables ESDIST (I,J),  
TFOES (I,J) I = 1, 2, . . . NPATCH, J = 1, 2, . . . NPT.

ESDIST (I,J): The distance from the transmitter along the great-circle path to the point (I,J). Note that ESDIST (I,1) must=PSTART(I) and ESDIST(I,NPT) must = PEND (I).

TFOES(I,J):  $f_o E_s$  at the point (I,J). Format 1X, 2F9.2.

## F. DATA-SET EXAMPLES

Three sets of examples are included at the end of this report to illustrate graphically the preparation of data sets in the form described above in Sec. E.

## G. PROGRAMS

Card decks of the FORTRAN source programs for both the data and ray-tracing programs are available from the Stanford Radioscience Laboratory.

## H. RUNNING THE PROGRAMS

To run the data program, prepare the appropriate data-input deck in the appropriate format, and submit this with the 7090 binary deck for the data program, along with the appropriate control cards for the FORTRAN MONITOR in use. (This varies with the 7090 installation.) Specify the tapes to be mounted on logical units 10 and 11. Naturally, if  $D_{sk}$  tables are to be read from tape, a specific tape must be mounted on unit 10. At the end of the run, unit 11 will contain the input data to be used by the ray-tracing program.

To run the ray-tracing program, mount the appropriate data tape on logical unit 11. Submit the 7090 binary deck for the ray-tracing program along with the appropriate FORTRAN MONITOR control cards. Output from this program appears on the "normal" FORTRAN output tape unit 6.

Neither program makes use of any sense switches or other console features.

## VII. CONCLUSIONS

In describing the reasons why the Kift-Fooks technique was chosen, how it would be used in the analysis of propagation data, and giving details of the program for use on a high-speed digital computer, no comparisons were made with actual records taken. It remained the intention of the authors to outline the work done here at Stanford and their reasons for doing it.

Comparison of ray tracings with experimental data has been done on several paths and the results of these comparisons are scheduled for another report.

Hopefully, the reader of this report will find sufficient information to enable him to reproduce this version of the ray-tracing program for use on available computers should he desire to do so. Duplicate decks of the program can be obtained from the authors by written request.

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## APPENDIX A. TERMINOLOGY

This Appendix has been taken directly from the "Report of the Lindau Meeting on Oblique Sounding of the Ionosphere," May 6-10, 1963. The recommendations listed below are to be submitted to URSI and are also scheduled to be published in the IQSY notes.

It was recognized that, for purposes of data interchange, a need exists for the standardization of certain terms. As a first step in this direction, the following recommendations are made.

1. Capital letters should be used in oblique-incidence work in contrast to the small letters agreed upon in vertical-incidence work.
2. In view of the ambiguity in the meaning of << usable >>, the term maximum usable frequency (MUF) should be eliminated in the description of oblique-incidence ionograms.
3. The use of the word "virtual path" should refer to the time of flight (group delay) in oblique propagation work.
4. In ray tracing the following symbols are suggested (Fig. A1).
  - a.  $\phi_o$  the angle of incidence at the bottom of the ionosphere.
  - b.  $\phi_r$  the angle of incidence, at the real height of reflection, of the extension of the linear ray path below the ionosphere.
  - c.  $i$  the angle between the ray path and the vertical at any point along the path.
  - d.  $\Delta$  the angle of elevation at the ground.

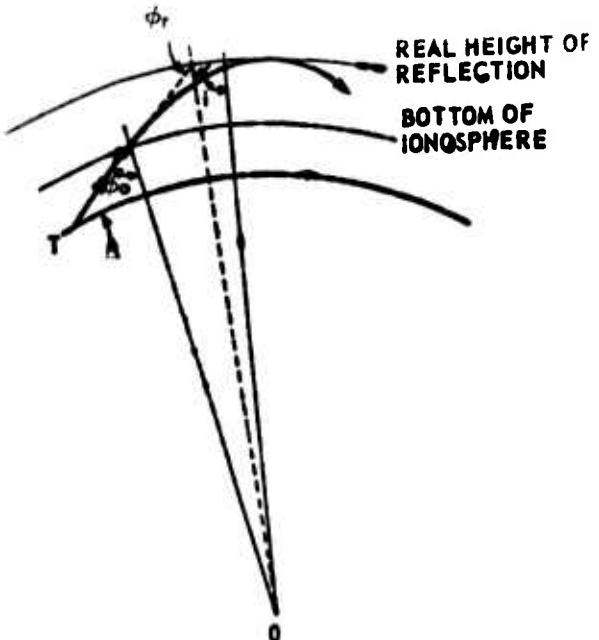


FIG. A1 RECOMMENDED RAY-PATH GEOMETRY.

The following terminology is suggested for the description of path structure (Fig. A2).

5. For propagation paths involving reflections by different layers, the reflections (or hops) should be specified in order of their position with respect to the transmitter. Thus 5E - 3F2 indicates five reflections from the E layer near the transmitter followed by three reflections from the F2 layer (Fig. A2-a).

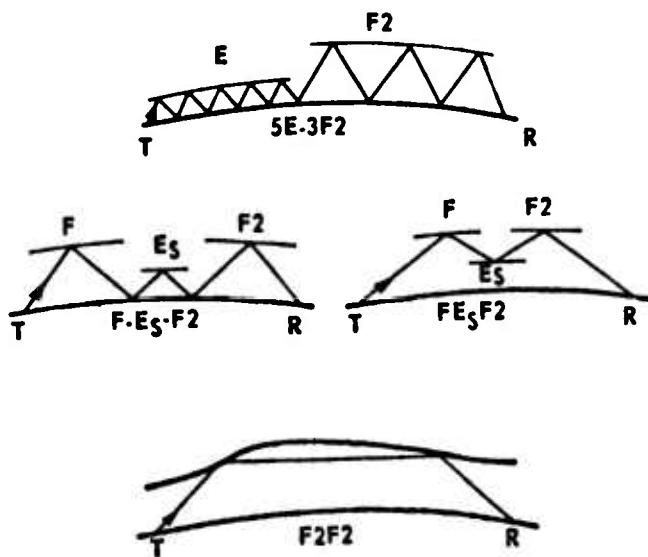


FIG. A2 RECOMMENDED MODE IDENTIFICATION.

6. The use of a dash is convenient for the representation of a ground reflection. The absence of a dash will then show up M-type ray paths and "supermodes." For example F - E<sub>s</sub> - F2 (Fig. A2-b) represents an F-layer hop followed by ground reflection to the lower side of the E<sub>s</sub> layer, reflection back to ground, then reflection to the lower side of the F2 layer and finally back to ground. On the other hand F E<sub>s</sub> F2 (Fig. A2-c) represents an M-type path in which the ray is reflected from the F layer to the upper side of the E<sub>s</sub> layer, back up to the lower side of the F2 layer and down to the ground. The symbol F2F2 (Fig. A2-d) means an F2 reflection followed by another F2 reflection without an intermediate ground reflection (supermode).

The following terms are suggested for the description of oblique ionograms (Fig. 13).

7. MOF (Maximum Observed Frequency) means the highest frequency on which the sounder-transmitter signals are observed on the ionogram, regardless of the propagation path involved.
8. LOF (Lowest Observed Frequency) means the lowest frequency on which the sounder-transmitter signals are observed on the ionogram, regardless of the propagation path involved.
9. These terms (MOF and LOF) may be used also to describe identifiable modes. For example 2F2 LCF means the lowest frequency (observed on the ionogram) which is propagated by two reflections at the F2 layer and an intermediate ground reflection. The 2F2 MOF means the highest observed frequency associated with two-hop F2 propagation, regardless of whether the signal is propagated by refraction, by scatter, or by a combination of both mechanisms.
10. The lowest observed frequency of the high-angle ray may be distinguished from that of the low-angle ray by the letters H and L respectively. Thus 2F2 HLOF is the lowest frequency (observed on the ionogram) of the signal that is propagated via the high-angle, two-hop, F2 path and 2F2 LLOF is the lowest frequency (observed on the ionogram) of the signal that is propagated by the low-angle, two-hop, F2 path.

11. The one-hop modes do not need the number 1(one) in front. For example, F2 LLOF means the low-angle ray LOF for the one-hop, F2 ray path.
12. When it is required to distinguish between the ordinary and extraordinary ray paths an "o" or "x" may follow in parentheses. The F2 MOF(x) is the maximum observed frequency of the extraordinary wave that is reflected once at the F2 layer.
13. Often the MOF for an identifiable path is greater than the frequency on which the regularly refracted components of the high-and low-angle rays join. It is suggested that the latter frequency be called the "junction frequency" and that it be denoted by JF.

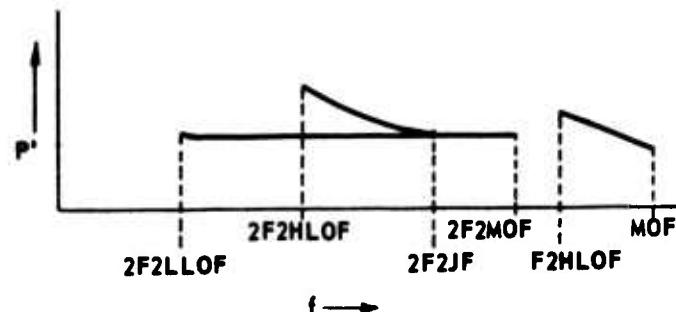


FIG. A3 RECOMMENDED IONOGram-SCALING PARAMETERS.

APPENDIX B. CALCULATION OF THE SUN'S ZENITH ANGLE,  $\chi$

$$\begin{aligned}\cos \chi &= \sin \lambda_1 \sin \lambda_2 + \cos \lambda_1 \cos \lambda_2 \cos (\theta_2 - \theta_1) \\ \sin \lambda_1 &= \sin \lambda_o \cos \left(\frac{d}{R}\right) + \cos \lambda_o \sin \left(\frac{d}{R}\right) \cos \alpha \\ \cot (\theta_1 - \theta_o) &= \left[ \sin \lambda_o \cos \alpha - \cos \lambda_o \cot \left(\frac{d}{R}\right) \right] \sin \alpha \\ \theta_2 &= \left[ \frac{(T-12)}{24} \right] \cdot 2\pi \text{ (neglecting equation of time)} \quad (B.1)\end{aligned}$$

where

$\lambda_o$  = latitude of transmitter

$\theta_o$  = longitude of transmitter

T = time in hours (U.T.)

$\lambda_2$  = declination of sun

$\alpha$  = bearing E. of N. of receiver from transmitter

$\theta_2$  = longitude of sun

$\lambda_1$  = latitude of point on path

$\theta_1$  = longitude of point on path

d = distance from transmitter to point on path

R = radius of earth

The data program computes  $\alpha$  and the path length, using the latitude and longitude of both the transmitting and receiving points and supplies the ray-tracing program with these parameters, in addition to the latitude and longitude of the transmitter. The data program also supplies a set of distances  $d_i$ , at roughly every 500 km along the path at which  $f_o F2$  and  $F2$  4000 MUF are supplied by the data program.

APPENDIX C. A METHOD FOR COMPUTING F2 LAYER HEIGHT  $h_m$  FROM  
VALUES OF  $f_o F_2$  AND  $F2\ 4000\ MUF$

A nomogram of height  $h_m$  versus the ratio of  $F2\ 4000\ MUF$  and  $f_o F_2$  for a parabolic layer with  $Y_m = 0.4 h_o$  is presented in the Fooks report [Ref. 12]. A polynomial expression, valid for

$$2.15 \leq \frac{F2\ 4000\ MUF}{f_o F_2} \leq 4.09, \quad (C.1)$$

which approximates the nomogram with maximum error in  $h_m$  of  $\pm 6$  km, is used in the program to compute  $h_m$ .

Let  $x = \frac{F2\ 4000\ MUF}{f_o F_2} = 1.1$  (M3000),

$$h_m = \left( \frac{2218.59}{x^{1.7083}} \right) + 19.44 (4.09 - x) (x - 2.15) + 46.0 (3.0 - x) (4.09 - x) (x - 2.15) \quad (C.2)$$

## APPENDIX D. CALCULATION OF REFLECTION HEIGHTS OF THE RAY IN A LAYER

The height of reflection  $h_r$  is calculated as follows:

$$h_r = h_o + Y_m \left[ 1 - \sqrt{1 - \left( \frac{f}{f_o} \cos i \right)^2} \right] \quad (D.1)$$

in the case of a ray reflecting from the bottom of a layer,  
and

$$h_r = h_o + 2Y_m - Y_m \left[ 1 - \sqrt{1 - \left( \frac{f}{f_o} \cos i \right)^2} \right] \quad (D.2)$$

in the case of a ray reflecting from the top of a layer.

The definition of the parameters is the same as in  
Eqs. (4) and (5).

## APPENDIX E. CALCULATION OF RAY ATTENUATION DUE TO D-LAYER ABSORPTION

The following expression, taken from RPU No. 9 [Ref. 21] is an estimate of the absorption in the D layer

$$DB = \frac{615.5 (1.0 + 0.0037 \cdot SSN) \cdot \cos^{1.3} (0.881\chi) \cdot N \cdot \sec \varphi_D}{(f + f_h)^{1.98}} \quad (E.1)$$

where

SSN = sunspot number

$\chi$  = sun's zenith angle

N = number of ray passages through the D layer

f = ray frequency

$\varphi_D$  = vertical angle which ray makes with the D layer

$f_h$  = gyro-frequency

DB = number of decibels of ray attenuation

In the ray-tracing program the D layer is assumed to be at a height of 70 km. This height plus ray take-off angle allows the calculation of  $\varphi_D$ . Since the program assumes a constant ray take-off angle, this quantity  $\varphi_D$  is computed only once for each mode. An average value of  $\cos \chi$  is used for each mode and an average value of  $f_h$  along the path is used in the calculation.

APPENDIX F. LISTING OF DATA AND RAY-TRACING PROGRAMS, SAMPLE  
OUTPUT AND INPUT FORMATS

The following figures consist of sample input data for the data program, a listing of the data program, a listing of the ray-trace program, and sample output from the ray-trace program.

EXAMPLE NUMBER 100. RAY TRACINGS ARE DESIRED FOR THE MONTH OF JUNE/1968  
BETWEEN A TRANSMITTER LOCATED AT 122.59 DEGREES WEST  
LONGITUDE AND 37.98 DEGREES NORTH LATITUDE - AND A  
RECEIVER LOCATED AT 15.75 DEGREES EAST LONGITUDE AND  
29.22 DEGREES SOUTH LATITUDE. THE RAY TRACING IS TO  
BE ACCOMPLISHED FOR THE ENTIRE 24 HOUR PERIOD.

IN ADDITION, RAY TRACINGS ARE DESIRED BETWEEN A  
TRANSMITTER AT 122.59 WEST AND A RECEIVER AT  
72.50 WEST AND 47.93 NORTH FOR THE HOURS 0900, 1200, 1500, 1800  
GMT.

IN BOTH CASES THE FREQUENCY RANGE TO BE TRACED IS  
4 TO 92 MC/S IN 2 MC/S STEPS. IN THE FIRST CASE TAKE  
OFF ANGLES APPROXIMATELY 45 DEGREES IN STEPS OF  
1 DEGREE WILL BE CONSIDERED. IN THE SECOND CASE  
TAKE-OFF ANGLES BETWEEN 0.24 AND 10.25 DEGREES IN  
STEPS OF 0.24 DEGREES WITH NO CONSIDERATION

THE NAUTICAL ALMANAC GIVES THE SUN DECLINATION  
AS -16.64 DEGREES FOR THE 15TH DAY OF THE MONTH OF  
JUNE/1968.

THE TABLES OF DISK ARE INSERTED HEREIN THE DISK FOR POF2 FIRST:  
IMMEDIATELY FOLLOWED BY THE DISK FOR THE 45000 FACTOR

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EXAMPLE NUMBER 200 THIS IS THE SAME AS EXAMPLE NUMBER 10 WITH THE  
EXCEPTION THAT THE DSK TABLES ARE ASSUMED TO BE ON  
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65 EXAMPLE NUMBER 500. RAY TRACINGS ARE DESIGNED BETWEEN A TRANSMITTER  
 66 LOCATED AT 92°05' W. 38°56' N AND A RECEIVER LOCATED  
 67 AT 15°45' E. 29°02' S. VERTICAL IONOSPHERIC SOUNDINGS  
 68 ARE AVAILABLE ALONG THE GREAT CIRCLE PATH FOR THE  
 69 HOURS 0619, 1030, 1245 AND 1430 GMT OF THE DAY IN  
 70 QUESTIONS THERE ARE 5 SETS OF VERTICAL SOUNDINGS.  
 71 THE FIRST IS TAKEN AT THE TRANSMITTER. THE SECOND  
 72 1000 KM FROM THE TRANSMITTER. THE THIRD 3750 KM FROM  
 73 THE TRANSMITTER. THE FOURTH 6900 KM FROM THE  
 74 TRANSMITTER AND THE FIFTH AT THE RECEIVER. THE TABLE  
 75 BELOW DESCRIBES THE MEASUREMENTS.  
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RANGE	FOF2	HF28F2 LAYER MAX WEIGHT
0	4.9	220.0
1000	6.2	245.0
3750	7.4	250.0
6300	7.8	252.0
RX	8.0	260.0

FOR 0015 GM<sup>T</sup>

RANGE	FOF2	HF28F2 LAYER MAX WEIGHT
0	8.2	220.0
1000	10.5	235.0
3750	11.7	230.0
6300	12.0	225.0
RX	12.5	227.0

FOR 1030 GM<sup>T</sup>

RANGE	FOF2	HF28F2 LAYER MAX WEIGHT
0	8.2	220.0
1000	10.5	235.0
3750	11.7	230.0
6300	12.0	225.0
RX	12.5	227.0

FOR 1430 GM<sup>T</sup>

RANGE	FOF2	HF28F2 LAYER MAX WEIGHT
0	11.0	237.0
1000	12.2	240.0

FOR 1800 GM<sup>T</sup>



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C DATA PREPARATION PROGRAM FOR RAY TRACE PROGRAM
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```

53      RETURN
18 GKA=52*V1*CX*21*SK*018
54
55 RETURN
END

```

```

2      C DATA PREPARATION PROGRAM FOR RAY TRACE PROGRAM
3      SUBROUTINE LATONITRLATY*TYLON,RLATY*PLON,PLONAZRTHEDIST*PLAT.
4
5      IPLOM=41
6      DIMENSION PDIST(100),PLAT(100),PLON(100)
7      PI=3.1415927
8      PI02=1.5707963
9      TUDP=6.2831853
10     DEGAD=PI/180.0
11     RADDG=180.0/PI
12     R=63107.0
13     TLLAT=DEGRAD*TYLAT
14     TLLON=DEGRAD*TYLON
15     RLATR=DEGRAD*RLATY
16     RYLONR=DEGRAD*RYLON
17     C=ABSF(TYLON-RLON)
18     IPIC=011 2*2.1
19     1 CTWOP1-C
20     2 AA=PI0V2*RYLAPR
21     BB=PI0V2*RLATE
22     CC=PI0SPRAN=COS(PH1)+SIN(PH1)*COS(TH1)*COS(FC1)
23     ARG=SGN(TH1)*COS(FC1)
24     ANG=ATAN(FC1)
25     SP1A01 3,4,4
26     3 ANGENDG01
27     4 PLRD=11*12*RADDEGANG
28     COTCOSPC/2,B1/SINFC/2*0
29     ANG=ATAN(F1*COTCOSPC/2,B1-SINFC/2*0.919)
30     ARG=ATAN(F1*COTCOSPC/2,B1+0.017*COSF1(AA+BB)/2*0.019)
31     ANG=ATAN(FC1)
32     IP1TLLON=PLON
33     5 ATNTRDGP1=A2*PI
34     6 IP1PLRM=3000.01 7.74

```





```

97
98      C2V=COSF2+0.0V1
99
100     DO 16 KAI=LIF
101
102     16 GFI=KA1GKA1SX+SY+S2Y+C1+C2+C3+C2V+KA+KF+LIF
103
104     DO 17 KAI=1M
105
106     17 GM1=KA1GKA1SX+SY+S2Y+C1+C2+C3+C2V+KA+KF+LIF
107
108     18 CONTINUF
109
110     19 00 31 1=1.NPTS
111
112     GM1=15.0*HOUR-180.0
113
114     TGMTRADEG=PLON(1)
115
116     IFIT=180.0 21.21.20
117
118     20 T=1-360.0
119
120     GO TO 23
121
122     21 IFIT=180.0 22.0.23.0.24
123
124     22 T=1+360.0
125
126     23 TRNGRAD=0
127
128     AO=0.0
129
130     DO 24 KAI=LIF
131
132     24 AO=AO+CFOF2(KA+1)*GF(1,KA)
133
134     FOF2=AO
135
136     DO 25 KAI=LIF
137
138     25 KAI=1.0
139
140     AIJ1=0.0
141
142     RIJI=0.0
143
144     DO 26 J=1,LHF
145
146     26 JSAC2=J-1
147
148     AIJ1=0.0
149
150     AIJ2=J-2
151
152     DO 27 KAI=LIF
153
154     27 KAI=1.0
155
156     G=GF11(KA)
157
158     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
159
160     DO 28 J=1,NPTS
161
162     28 J=NHF+1
163
164     LM=NM+1
165
166     NM=NM+1
167
168     AIJ1=AIJ1+CFOF2(KA,J5B1*G
169
170     DO 29 KAI=LIF
171
172     29 KAI=1.0
173
174     G=GF11(KA)
175
176     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
177
178     DO 30 J=1,NPTS
179
180     30 J=NHF+1
181
182     LM=NM+1
183
184     NM=NM+1
185
186     AIJ1=AIJ1+CFOF2(KA,J5B1*G
187
188     DO 31 KAI=LIF
189
190     31 KAI=1.0
191
192     G=GF11(KA)
193
194     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
195
196     DO 32 J=1,NPTS
197
198     32 J=NHF+1
199
200     LM=NM+1
201
202     NM=NM+1
203
204     AIJ1=AIJ1+CFOF2(KA,J5B1*G
205
206     DO 33 KAI=LIF
207
208     33 KAI=1.0
209
210     G=GF11(KA)
211
212     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
213
214     DO 34 J=1,NPTS
215
216     34 J=NHF+1
217
218     LM=NM+1
219
220     NM=NM+1
221
222     AIJ1=AIJ1+CFOF2(KA,J5B1*G
223
224     DO 35 KAI=LIF
225
226     35 KAI=1.0
227
228     G=GF11(KA)
229
230     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
231
232     DO 36 J=1,NPTS
233
234     36 J=NHF+1
235
236     LM=NM+1
237
238     NM=NM+1
239
240     AIJ1=AIJ1+CFOF2(KA,J5B1*G
241
242     DO 37 KAI=LIF
243
244     37 KAI=1.0
245
246     G=GF11(KA)
247
248     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
249
250     DO 38 J=1,NPTS
251
252     38 J=NHF+1
253
254     LM=NM+1
255
256     NM=NM+1
257
258     AIJ1=AIJ1+CFOF2(KA,J5B1*G
259
260     DO 39 KAI=LIF
261
262     39 KAI=1.0
263
264     G=GF11(KA)
265
266     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
267
268     DO 40 J=1,NPTS
269
270     40 J=NHF+1
271
272     LM=NM+1
273
274     NM=NM+1
275
276     AIJ1=AIJ1+CFOF2(KA,J5B1*G
277
278     DO 41 KAI=LIF
279
280     41 KAI=1.0
281
282     G=GF11(KA)
283
284     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
285
286     DO 42 J=1,NPTS
287
288     42 J=NHF+1
289
290     LM=NM+1
291
292     NM=NM+1
293
294     AIJ1=AIJ1+CFOF2(KA,J5B1*G
295
296     DO 43 KAI=LIF
297
298     43 KAI=1.0
299
300     G=GF11(KA)
301
302     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
303
304     DO 44 J=1,NPTS
305
306     44 J=NHF+1
307
308     LM=NM+1
309
310     NM=NM+1
311
312     AIJ1=AIJ1+CFOF2(KA,J5B1*G
313
314     DO 45 KAI=LIF
315
316     45 KAI=1.0
317
318     G=GF11(KA)
319
320     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
321
322     DO 46 J=1,NPTS
323
324     46 J=NHF+1
325
326     LM=NM+1
327
328     NM=NM+1
329
330     AIJ1=AIJ1+CFOF2(KA,J5B1*G
331
332     DO 47 KAI=LIF
333
334     47 KAI=1.0
335
336     G=GF11(KA)
337
338     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
339
340     DO 48 J=1,NPTS
341
342     48 J=NHF+1
343
344     LM=NM+1
345
346     NM=NM+1
347
348     AIJ1=AIJ1+CFOF2(KA,J5B1*G
349
350     DO 49 KAI=LIF
351
352     49 KAI=1.0
353
354     G=GF11(KA)
355
356     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
357
358     DO 50 J=1,NPTS
359
360     50 J=NHF+1
361
362     LM=NM+1
363
364     NM=NM+1
365
366     AIJ1=AIJ1+CFOF2(KA,J5B1*G
367
368     DO 51 KAI=LIF
369
370     51 KAI=1.0
371
372     G=GF11(KA)
373
374     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
375
376     DO 52 J=1,NPTS
377
378     52 J=NHF+1
379
380     LM=NM+1
381
382     NM=NM+1
383
384     AIJ1=AIJ1+CFOF2(KA,J5B1*G
385
386     DO 53 KAI=LIF
387
388     53 KAI=1.0
389
390     G=GF11(KA)
391
392     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
393
394     DO 54 J=1,NPTS
395
396     54 J=NHF+1
397
398     LM=NM+1
399
400     NM=NM+1
401
402     AIJ1=AIJ1+CFOF2(KA,J5B1*G
403
404     DO 55 KAI=LIF
405
406     55 KAI=1.0
407
408     G=GF11(KA)
409
410     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
411
412     DO 56 J=1,NPTS
413
414     56 J=NHF+1
415
416     LM=NM+1
417
418     NM=NM+1
419
420     AIJ1=AIJ1+CFOF2(KA,J5B1*G
421
422     DO 57 KAI=LIF
423
424     57 KAI=1.0
425
426     G=GF11(KA)
427
428     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
429
430     DO 58 J=1,NPTS
431
432     58 J=NHF+1
433
434     LM=NM+1
435
436     NM=NM+1
437
438     AIJ1=AIJ1+CFOF2(KA,J5B1*G
439
440     DO 59 KAI=LIF
441
442     59 KAI=1.0
443
444     G=GF11(KA)
445
446     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
447
448     DO 60 J=1,NPTS
449
450     60 J=NHF+1
451
452     LM=NM+1
453
454     NM=NM+1
455
456     AIJ1=AIJ1+CFOF2(KA,J5B1*G
457
458     DO 61 KAI=LIF
459
460     61 KAI=1.0
461
462     G=GF11(KA)
463
464     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
465
466     DO 62 J=1,NPTS
467
468     62 J=NHF+1
469
470     LM=NM+1
471
472     NM=NM+1
473
474     AIJ1=AIJ1+CFOF2(KA,J5B1*G
475
476     DO 63 KAI=LIF
477
478     63 KAI=1.0
479
480     G=GF11(KA)
481
482     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
483
484     DO 64 J=1,NPTS
485
486     64 J=NHF+1
487
488     LM=NM+1
489
490     NM=NM+1
491
492     AIJ1=AIJ1+CFOF2(KA,J5B1*G
493
494     DO 65 KAI=LIF
495
496     65 KAI=1.0
497
498     G=GF11(KA)
499
500     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
501
502     DO 66 J=1,NPTS
503
504     66 J=NHF+1
505
506     LM=NM+1
507
508     NM=NM+1
509
510     AIJ1=AIJ1+CFOF2(KA,J5B1*G
511
512     DO 67 KAI=LIF
513
514     67 KAI=1.0
515
516     G=GF11(KA)
517
518     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
519
520     DO 68 J=1,NPTS
521
522     68 J=NHF+1
523
524     LM=NM+1
525
526     NM=NM+1
527
528     AIJ1=AIJ1+CFOF2(KA,J5B1*G
529
530     DO 69 KAI=LIF
531
532     69 KAI=1.0
533
534     G=GF11(KA)
535
536     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
537
538     DO 70 J=1,NPTS
539
540     70 J=NHF+1
541
542     LM=NM+1
543
544     NM=NM+1
545
546     AIJ1=AIJ1+CFOF2(KA,J5B1*G
547
548     DO 71 KAI=LIF
549
550     71 KAI=1.0
551
552     G=GF11(KA)
553
554     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
555
556     DO 72 J=1,NPTS
557
558     72 J=NHF+1
559
560     LM=NM+1
561
562     NM=NM+1
563
564     AIJ1=AIJ1+CFOF2(KA,J5B1*G
565
566     DO 73 KAI=LIF
567
568     73 KAI=1.0
569
570     G=GF11(KA)
571
572     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
573
574     DO 74 J=1,NPTS
575
576     74 J=NHF+1
577
578     LM=NM+1
579
580     NM=NM+1
581
582     AIJ1=AIJ1+CFOF2(KA,J5B1*G
583
584     DO 75 KAI=LIF
585
586     75 KAI=1.0
587
588     G=GF11(KA)
589
590     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
591
592     DO 76 J=1,NPTS
593
594     76 J=NHF+1
595
596     LM=NM+1
597
598     NM=NM+1
599
600     AIJ1=AIJ1+CFOF2(KA,J5B1*G
601
602     DO 77 KAI=LIF
603
604     77 KAI=1.0
605
606     G=GF11(KA)
607
608     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
609
610     DO 78 J=1,NPTS
611
612     78 J=NHF+1
613
614     LM=NM+1
615
616     NM=NM+1
617
618     AIJ1=AIJ1+CFOF2(KA,J5B1*G
619
620     DO 79 KAI=LIF
621
622     79 KAI=1.0
623
624     G=GF11(KA)
625
626     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
627
628     DO 80 J=1,NPTS
629
630     80 J=NHF+1
631
632     LM=NM+1
633
634     NM=NM+1
635
636     AIJ1=AIJ1+CFOF2(KA,J5B1*G
637
638     DO 81 KAI=LIF
639
640     81 KAI=1.0
641
642     G=GF11(KA)
643
644     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
645
646     DO 82 J=1,NPTS
647
648     82 J=NHF+1
649
650     LM=NM+1
651
652     NM=NM+1
653
654     AIJ1=AIJ1+CFOF2(KA,J5B1*G
655
656     DO 83 KAI=LIF
657
658     83 KAI=1.0
659
660     G=GF11(KA)
661
662     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
663
664     DO 84 J=1,NPTS
665
666     84 J=NHF+1
667
668     LM=NM+1
669
670     NM=NM+1
671
672     AIJ1=AIJ1+CFOF2(KA,J5B1*G
673
674     DO 85 KAI=LIF
675
676     85 KAI=1.0
677
678     G=GF11(KA)
679
680     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
681
682     DO 86 J=1,NPTS
683
684     86 J=NHF+1
685
686     LM=NM+1
687
688     NM=NM+1
689
690     AIJ1=AIJ1+CFOF2(KA,J5B1*G
691
692     DO 87 KAI=LIF
693
694     87 KAI=1.0
695
696     G=GF11(KA)
697
698     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
699
700     DO 88 J=1,NPTS
701
702     88 J=NHF+1
703
704     LM=NM+1
705
706     NM=NM+1
707
708     AIJ1=AIJ1+CFOF2(KA,J5B1*G
709
710     DO 89 KAI=LIF
711
712     89 KAI=1.0
713
714     G=GF11(KA)
715
716     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
717
718     DO 90 J=1,NPTS
719
720     90 J=NHF+1
721
722     LM=NM+1
723
724     NM=NM+1
725
726     AIJ1=AIJ1+CFOF2(KA,J5B1*G
727
728     DO 91 KAI=LIF
729
730     91 KAI=1.0
731
732     G=GF11(KA)
733
734     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
735
736     DO 92 J=1,NPTS
737
738     92 J=NHF+1
739
740     LM=NM+1
741
742     NM=NM+1
743
744     AIJ1=AIJ1+CFOF2(KA,J5B1*G
745
746     DO 93 KAI=LIF
747
748     93 KAI=1.0
749
750     G=GF11(KA)
751
752     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
753
754     DO 94 J=1,NPTS
755
756     94 J=NHF+1
757
758     LM=NM+1
759
760     NM=NM+1
761
762     AIJ1=AIJ1+CFOF2(KA,J5B1*G
763
764     DO 95 KAI=LIF
765
766     95 KAI=1.0
767
768     G=GF11(KA)
769
770     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
771
772     DO 96 J=1,NPTS
773
774     96 J=NHF+1
775
776     LM=NM+1
777
778     NM=NM+1
779
780     AIJ1=AIJ1+CFOF2(KA,J5B1*G
781
782     DO 97 KAI=LIF
783
784     97 KAI=1.0
785
786     G=GF11(KA)
787
788     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
789
790     DO 98 J=1,NPTS
791
792     98 J=NHF+1
793
794     LM=NM+1
795
796     NM=NM+1
797
798     AIJ1=AIJ1+CFOF2(KA,J5B1*G
799
800     DO 99 KAI=LIF
801
802     99 KAI=1.0
803
804     G=GF11(KA)
805
806     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
807
808     DO 100 J=1,NPTS
809
810     100 J=NHF+1
811
812     LM=NM+1
813
814     NM=NM+1
815
816     AIJ1=AIJ1+CFOF2(KA,J5B1*G
817
818     DO 101 KAI=LIF
819
820     101 KAI=1.0
821
822     G=GF11(KA)
823
824     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
825
826     DO 102 J=1,NPTS
827
828     102 J=NHF+1
829
830     LM=NM+1
831
832     NM=NM+1
833
834     AIJ1=AIJ1+CFOF2(KA,J5B1*G
835
836     DO 103 KAI=LIF
837
838     103 KAI=1.0
839
840     G=GF11(KA)
841
842     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
843
844     DO 104 J=1,NPTS
845
846     104 J=NHF+1
847
848     LM=NM+1
849
850     NM=NM+1
851
852     AIJ1=AIJ1+CFOF2(KA,J5B1*G
853
854     DO 105 KAI=LIF
855
856     105 KAI=1.0
857
858     G=GF11(KA)
859
860     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
861
862     DO 106 J=1,NPTS
863
864     106 J=NHF+1
865
866     LM=NM+1
867
868     NM=NM+1
869
870     AIJ1=AIJ1+CFOF2(KA,J5B1*G
871
872     DO 107 KAI=LIF
873
874     107 KAI=1.0
875
876     G=GF11(KA)
877
878     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
879
880     DO 108 J=1,NPTS
881
882     108 J=NHF+1
883
884     LM=NM+1
885
886     NM=NM+1
887
888     AIJ1=AIJ1+CFOF2(KA,J5B1*G
889
890     DO 109 KAI=LIF
891
892     109 KAI=1.0
893
894     G=GF11(KA)
895
896     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
897
898     DO 110 J=1,NPTS
899
900     110 J=NHF+1
901
902     LM=NM+1
903
904     NM=NM+1
905
906     AIJ1=AIJ1+CFOF2(KA,J5B1*G
907
908     DO 111 KAI=LIF
909
910     111 KAI=1.0
911
912     G=GF11(KA)
913
914     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
915
916     DO 112 J=1,NPTS
917
918     112 J=NHF+1
919
920     LM=NM+1
921
922     NM=NM+1
923
924     AIJ1=AIJ1+CFOF2(KA,J5B1*G
925
926     DO 115 KAI=LIF
927
928     115 KAI=1.0
929
930     G=GF11(KA)
931
932     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
933
934     DO 116 J=1,NPTS
935
936     116 J=NHF+1
937
938     LM=NM+1
939
940     NM=NM+1
941
942     AIJ1=AIJ1+CFOF2(KA,J5B1*G
943
944     DO 117 KAI=LIF
945
946     117 KAI=1.0
947
948     G=GF11(KA)
949
950     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
951
952     DO 118 J=1,NPTS
953
954     118 J=NHF+1
955
956     LM=NM+1
957
958     NM=NM+1
959
960     AIJ1=AIJ1+CFOF2(KA,J5B1*G
961
962     DO 119 KAI=LIF
963
964     119 KAI=1.0
965
966     G=GF11(KA)
967
968     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
969
970     DO 120 J=1,NPTS
971
972     120 J=NHF+1
973
974     LM=NM+1
975
976     NM=NM+1
977
978     AIJ1=AIJ1+CFOF2(KA,J5B1*G
979
980     DO 121 KAI=LIF
981
982     121 KAI=1.0
983
984     G=GF11(KA)
985
986     AIJ1=AIJ1+CFOF2(KA,JSAC1*G
987
988     DO 122 J=1,NPTS
989
990     122 J=NHF+1
991
992     LM=NM+1
993
994     NM=NM+1
995
996     AIJ1=AIJ1+CFOF2(KA,J5B1*G
997
998     DO 123 KAI=LIF
999
1000    123 KAI=1.0
1001
1002    G=GF11(KA)
1003
1004    AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1005
1006    DO 124 J=1,NPTS
1007
1008    124 J=NHF+1
1009
1010   NM=NM+1
1011
1012   AIJ1=AIJ1+CFOF2(KA,J5B1*G
1013
1014   DO 125 KAI=LIF
1015
1016   125 KAI=1.0
1017
1018   G=GF11(KA)
1019
1020   AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1021
1022   DO 126 J=1,NPTS
1023
1024   126 J=NHF+1
1025
1026   NM=NM+1
1027
1028   AIJ1=AIJ1+CFOF2(KA,J5B1*G
1029
1030   DO 127 KAI=LIF
1031
1032   127 KAI=1.0
1033
1034   G=GF11(KA)
1035
1036   AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1037
1038   DO 128 J=1,NPTS
1039
1040   128 J=NHF+1
1041
1042   LM=NM+1
1043
1044   NM=NM+1
1045
1046   AIJ1=AIJ1+CFOF2(KA,J5B1*G
1047
1048   DO 129 KAI=LIF
1049
1050   129 KAI=1.0
1051
1052   G=GF11(KA)
1053
1054   AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1055
1056   DO 130 J=1,NPTS
1057
1058   130 J=NHF+1
1059
1060   LM=NM+1
1061
1062   NM=NM+1
1063
1064   AIJ1=AIJ1+CFOF2(KA,J5B1*G
1065
1066   DO 131 KAI=LIF
1067
1068   131 KAI=1.0
1069
1070   G=GF11(KA)
1071
1072   AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1073
1074   DO 132 J=1,NPTS
1075
1076   132 J=NHF+1
1077
1078   LM=NM+1
1079
1080   NM=NM+1
1081
1082   AIJ1=AIJ1+CFOF2(KA,J5B1*G
1083
1084   DO 133 KAI=LIF
1085
1086   133 KAI=1.0
1087
1088   G=GF11(KA)
1089
1090   AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1091
1092   DO 134 J=1,NPTS
1093
1094   134 J=NHF+1
1095
1096   LM=NM+1
1097
1098   NM=NM+1
1099
1100  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1101
1102  DO 135 KAI=LIF
1103
1104  135 KAI=1.0
1105
1106  G=GF11(KA)
1107
1108  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1109
1110  DO 136 J=1,NPTS
1111
1112  136 J=NHF+1
1113
1114  LM=NM+1
1115
1116  NM=NM+1
1117
1118  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1119
1120  DO 137 KAI=LIF
1121
1122  137 KAI=1.0
1123
1124  G=GF11(KA)
1125
1126  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1127
1128  DO 138 J=1,NPTS
1129
1130  138 J=NHF+1
1131
1132  LM=NM+1
1133
1134  NM=NM+1
1135
1136  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1137
1138  DO 139 KAI=LIF
1139
1140  139 KAI=1.0
1141
1142  G=GF11(KA)
1143
1144  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1145
1146  DO 140 J=1,NPTS
1147
1148  140 J=NHF+1
1149
1150  LM=NM+1
1151
1152  NM=NM+1
1153
1154  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1155
1156  DO 141 KAI=LIF
1157
1158  141 KAI=1.0
1159
1160  G=GF11(KA)
1161
1162  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1163
1164  DO 142 J=1,NPTS
1165
1166  142 J=NHF+1
1167
1168  LM=NM+1
1169
1170  NM=NM+1
1171
1172  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1173
1174  DO 143 KAI=LIF
1175
1176  143 KAI=1.0
1177
1178  G=GF11(KA)
1179
1180  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1181
1182  DO 144 J=1,NPTS
1183
1184  144 J=NHF+1
1185
1186  LM=NM+1
1187
1188  NM=NM+1
1189
1190  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1191
1192  DO 145 KAI=LIF
1193
1194  145 KAI=1.0
1195
1196  G=GF11(KA)
1197
1198  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1199
1200  DO 146 J=1,NPTS
1201
1202  146 J=NHF+1
1203
1204  LM=NM+1
1205
1206  NM=NM+1
1207
1208  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1209
1210  DO 147 KAI=LIF
1211
1212  147 KAI=1.0
1213
1214  G=GF11(KA)
1215
1216  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1217
1218  DO 148 J=1,NPTS
1219
1220  148 J=NHF+1
1221
1222  LM=NM+1
1223
1224  NM=NM+1
1225
1226  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1227
1228  DO 149 KAI=LIF
1229
1230  149 KAI=1.0
1231
1232  G=GF11(KA)
1233
1234  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1235
1236  DO 150 J=1,NPTS
1237
1238  150 J=NHF+1
1239
1240  LM=NM+1
1241
1242  NM=NM+1
1243
1244  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1245
1246  DO 151 KAI=LIF
1247
1248  151 KAI=1.0
1249
1250  G=GF11(KA)
1251
1252  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1253
1254  DO 152 J=1,NPTS
1255
1256  152 J=NHF+1
1257
1258  LM=NM+1
1259
1260  NM=NM+1
1261
1262  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1263
1264  DO 153 KAI=LIF
1265
1266  153 KAI=1.0
1267
1268  G=GF11(KA)
1269
1270  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1271
1272  DO 154 J=1,NPTS
1273
1274  154 J=NHF+1
1275
1276  LM=NM+1
1277
1278  NM=NM+1
1279
1280  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1281
1282  DO 155 KAI=LIF
1283
1284  155 KAI=1.0
1285
1286  G=GF11(KA)
1287
1288  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1289
1290  DO 156 J=1,NPTS
1291
1292  156 J=NHF+1
1293
1294  LM=NM+1
1295
1296  NM=NM+1
1297
1298  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1299
1300  DO 157 KAI=LIF
1301
1302  157 KAI=1.0
1303
1304  G=GF11(KA)
1305
1306  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1307
1308  DO 158 J=1,NPTS
1309
1310  158 J=NHF+1
1311
1312  LM=NM+1
1313
1314  NM=NM+1
1315
1316  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1317
1318  DO 159 KAI=LIF
1319
1320  159 KAI=1.0
1321
1322  G=GF11(KA)
1323
1324  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1325
1326  DO 160 J=1,NPTS
1327
1328  160 J=NHF+1
1329
1330  LM=NM+1
1331
1332  NM=NM+1
1333
1334  AIJ1=AIJ1+CFOF2(KA,J5B1*G
1335
1336  DO 161 KAI=LIF
1337
1338  161 KAI=1.0
1339
1340  G=GF11(KA)
1341
1342  AIJ1=AIJ1+CFOF2(KA,JSAC1*G
1343
1344  DO 162 J=1,NPTS
1345
1346  162 J=NHF+1
1347
1348  LM=NM+1
134
```



```

      READ INPUT TAPE 5,65,1ES
      45 FORMAT(1I3
      IF(1ES< 48+46+43
      46 WRITE OUTPUT TAPE 11+32+(ES,FREQ0,FREQD,ANGLE,ANGLE
      4601 WRITE OUTPUT TAPE 11,3201,NCHT
      IF(NCHT)< 47+47+4602
      4602 DO 4603 I=1,NCHT
      4603 WRITE OUTPUT TAPE 11,3204,HFREQ(1)
      47 ISETS=1SETS+1
      (F1)SETS-NSETS1 39+39+2
      48 WRITE OUTPUT TAPE 11+45+1ES
      READ INPUT TAPE 5,49,NPATCH
      49 FORMAT(1A1
      READ INPUT TAPE 5,50,IPSTART(1),PEND(1,(=1,NPATCH)
      50 FORMAT(1X+2F9+2)
      WRITE OUTPUT TAPE 11+49+NPATCH
      WRITE OUTPUT TAPE 11+50,IPSTART(1),PEND(1,(=1,NPATCH)
      209
      0D 52 I=1,NPATCH
      READ INPUT TAPE 5,49,NPT
      READ INPUT TAPE 5,51,ESDIST(1,J),TFOES(1,J)=1,NPT)
      51 FORMAT(1X,F8.2+1X,F5.2)
      WRITE OUTPUT TAPE 11+49,NPT
      52 WRITE OUTPUT TAPE 11+81,ESD(ST(1,J),TFOES((J),J=1,NPT)
      WRITE OUTPUT TAPE 11+93,FRFOL,FRFOD,ANGLE,ANGLE
      53 FORMAT(13F7.3/3F7.3)
      GO TO 4601
      END

```

```

1      C STANFORD RAY TRACE PROGRAM
2      FUNCTION COSCH (PHIO,THETAO,T,PM12,ALPHA,D)
3      PI=3.1415927
4      SINPHO=SIN (PHIO)
5      COSPHO=COS (PHIO)
6      COSALP=COSF (ALPHA)
7      SINPHI=SINPHO*COSF(D)+COSPHO*SINF(D)
8      COT=(SINPHO*COSALP-COSPHO*COSF(D))/SINF(D)/SINF(ALPHA)
9      ATANG=ATANF(1.0/COT)
10     IF(ALPHA-PI) 1,4,4
11     1 IF(ATANG) 2,3,3
12     2 THETAI=THETAO+ATANG
13     GO TO 7
14     3 THETAI=THETAO+ATANG-PI
15     GO TO 7
16     4 IF(ATANG) 6,6,5
17     5 THETAI=THETAO+ATANG
18     GO TO 7
19     6 THETAI=THETAO+PI+ATANG
20     7 THETA2=(T-12.0)*10*(3.1415927/12.0)
21     COSCH=SINPHI*SINF(PHI2)+COSF(ATANF(SINPHI/S2RTF11.0-SINPHI100*211))*
22     1COSF(PHI2)*COSF(ATETA2-THETAI)
23     RETURN
24     END

```

```

1      C STANFORD RAY TRACE PROGRAM
2      SUBROUTINE DNEF
3      COMMON REFIND,FREQ,FC,I-REFL,M1,M2,MM,VN,COST
4      IPIFOI 2+12
5      1 IREFL=9
6      M1=MM-VN
7      RETURN
8      2 REFIND=FREQ/POLE*COST
9      IPIREFIND=1.01 3.669
10     3 IREFL=1
11     M1=MM+VN
12     RETURN
13     4 IREFL=4
14     RETURN
15     5 IPIREFIND=2.01 7.76
16     6 IREFL=9
17     M1=MM-VN
18     RETURN
19     7 IREFL=2
20     M1=MM+VN
21     RETURN
22     END

```

1 C STANFORD RAY TRACE PROGRAM
 2 SUBROUTINE UPREF
 3 COMMON REFIND,FREQ,FC,I-REFL,M1,M2,MM,VN,COST
 4 IPIFOI 2+12
 5 1 IREFL=3
 6 M2=MM+VN
 7 RETURN
 8 2 REFIND=IREFL\*POLE\*COST
 9 IPIREFIND=1.01 3.669
 10 3 IREFL=1
 11 M1=MM+VN
 12 RETURN
 13 4 IREFL=4
 14 RETURN
 15 5 IPIREFIND=2.01 7.76
 16 6 IREFL=9
 17 M1=MM-VN
 18 RETURN
 19 7 IREFL=2
 20 M1=MM+VN
 21 RETURN
 22 END



STANFORD RAY TRACE PROGRAM

SUBROUTINE CALCFIT15(F1,F0)

DIMENSION A(1200)

INDEX=KPFTR(15157100,0902)

F03A1INDEX

F02A1INDEX+3

FINDEX=INDEX

F0=F01+RT015\*F170+RT15D2\*RT01+RT15D3\*RT02+F01

RETURN

END

STANFORD RAY TRACE PROGRAM

2  
3 SUBROUTINE CALCFIT15(F1,F0)

4 INDEX=A(1200)

5 F03A1INDEX

6 F02A1INDEX+3

7 FINDEX=INDEX

8 F0=F01+RT015\*F170+RT15D2\*RT01+RT15D3\*RT02+F01

9 COMMENT INPUT FOR IONOSPHERIC GENERATORS

10 COMMON RNAME,PRE,PRO,IRFLM,GMH,MOMTH,COSI,PDIST,SDSH,TRCRP

11 J,PRDP,PRCP,RLCK,K,INT,ISHP,BMNP,NAMP,ANG1,ANG2,LAYR,FLAYR,R,

12 SCOS,ANGLE,IPRC00

13 DIMENSION RLDP1001,FLDP1001,QUOTEM1001,PRNAME1001,PRNAME15001

14 DIMENSION PRDP2000,PRCP2000,TFOR192001,PRCP2000,TMTR2001

15 DIMENSION PRDP1500,PRCP1500,PRDP192001,PRCP192001,PRX28501

16 DIMENSION PSTART(20),PENO(20),FS005,FS200,TFOES920,FS00

17 DIMENSION AGDIS12001,AGTAB2009,AMDOE12003

18 DIMENSION OLVTP12001,FRTP12001,PRDNW1329

19 DIMENSION HOLD1150,101,HOLD141850,101,HOLD121930,101,HOLD1150,101,HOLD141850,101,HOLD121930,101

20 REMINO 81

21 R=6367.0

22 K=0

23 1 READ INPUT TAP11.2,FNAME,ITYPE

2 FORMAT(10A6.15)

24 JK=0

25 KL=0

26 IPEN=0

27 00 5 1=1,200

28 TFOR1110C,0

29 TFOR1110N,0

30 TFOR2111N,0

31 TFOR2111=0,0

32 9 THT11)=0,0

```

DO 6 I=1,N
 9013 DO 10 I=1,N
 10 MT(1)=MTUNIF(MUL(1)/(FOF2(1)))
 65
 34
 35      COMMENT GENERATE E LAYER
 36      1N01 HME=120.0
 66
 67
 68      YME=20.0
 69
 70      D=0.0
 71      1+1
 72      SUMCOS=0.0
 73      11 IF(I=PLEN) 12+12+13
 74      12 COSX*COSCH (FLNR*FLATR*FLMR*T*OECR,BERR*D/R)
 75      TFOE(1)=TDEISSN(COSH)
 76      D=D+100.0
 77      1+1+1
 78      IF(COSX) 1201+1202+1202
 79
 80      1201 COSX=0.0
 81      1202 SUMCOS=SUMCOS+COSX
 82      GO TO 11
 83      13 HME=1-1
 84      AVCOS=SUMCOS/FLOAT(HME)
 85      IF(AVCDS) 1200+1299+1900
 86
 87      1200 COSCH=C0.0
 88      1299 DO 1301
 89      1300 COSCH=COS(10.881*AVCSINH(SAT(F1,0-AVCOS*211)*1.3)
 90      1301 DI=1.0+0.0037551*CDSCM1
 91
 92      COMMENT GENERATE F1 LAYER
 93      HMFI=210.0
 94      VMFLSN=0
 95      DO 14 I=1,MF
 96      14 TFOF11=OF1*FOE111
 97      14 TFOF11=OF1*FOE111
 98      COMMENT GENERATE F2 LAYER
 99
 100      DO 901 1=1,N
 101      901 FOF2(1)=OF2(1)
 102      901 IF (TYPE=1) 9013,9013,1001
 103      901
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97      2201 D=0+100.0
      COMMENT GENERATE ES LAYERS, IF ANY
      98      129
      99      READ INPUT TAPE11+J+1ES
      100      130
      23 FORMAT1X.121
      101      131
      IF1ES1 24+31+24
      102      132
      J2=J+2      103      133
      #DJ#PRO1$T(J)/PL2NGT      PSTART11=0.0
      #DJ1=R01$P(J1)/PLEN$      104      134
      #DJ2=RDI$T(J2)/PLEN$      DD 26 1=1,20
      CALL POLYRDJ,FOF2(J1,0,JDJ1,0,DF21,J11,0,DJ2,0,OF21,J11,A1,B1,C11
      105      135
      CALL POLYRDJ,ANT(J1,0,RDJ1,0,HT1,J11,0,RDJ2,0,MT1,J21,A2,B2,C2)
      106      136
      ESO1ST((1+j))=0,0
      107      137
      1501 T01(DPLN$T),RDJ21 16+16+17
      108      138
      16 X=0,PLFNGT      109      139
      TFOE21K1=((A1*X+B1)*X)+C1      READ INPUT TAPE11+28,(PSTART11,1=1,NPATCH)
      TH1(K)=(A2*X+B2)*X+C2      110      140
      111      141
      28 FORMAT1X.131      READ INPUT TAPE11+27,NPATCH
      112      142
      WRITE OUTPUT TAPE 6+2807      27 FORMAT1X.131
      113      143
      2801 FORMAT1H0,38HES PATCHES PRESENT/1H0+33NPATCH STARTS AT PATCH 146
      114      144
      1ENDS AT)      28 FORMAT1X.2F9,21
      115      145
      2802 FORMAT1H0+4X,F8.2+12Z+FB+21      WRITE OUTPUT TAPE 6+2802,(PSTART11,1=1,NPATCH)
      116      146
      DD 19 PCK+200      117      147
      117      148
      19 THP(1)=THP1K-1      2002 FORMAT1H0+4X,F8.2+12Z+FB+21
      TFOE$11=TFOE1K-1      118      149
      TFOE$119=TFOE1K-10      00 3001 1=1,NPATCH
      TFOE$211=TFOE21K-11      119      150
      120      151
      19 THP(1)=THP1K-11      READ INPUT TAPE11+29,NPYS
      WRITE OUTPUT TAPE 6+20,FMNAME      20 FORMAT1H1+23HIONDSFRIC PROFILE FOR1GA60
      211      152
      212      153
      20 FORMAT1H1+23HIONDSFRIC PROFILE FOR1GA60      READ INPUT TAPE11+30+16SDIST11,J1+1,NPTSL
      121      154
      122      155
      123      156
      29 FORMAT1Hn+X+34HF0E FOF? MY FOF2 RANGES      31 NAME$=100,n
      124      157
      125      COMMENT ALPHA-NUMERIC EQUIVALENTS OF KODE REFLECTION NAMES
      126      158
      127      159
      DO 2201 J=1,K      FRAME$11+3M,FS
      WRITE OUTPUT TAPE 6+22+1FNE(J1,TFOE11,J1,TFOE21,J1,TNT1,J1,0      FRAME$21+3H,E
      22 FORMAT1H0,F4+1.2X+P4+3.2X,F4+1.9X+P6+2.9X+P8+2.9      FRAME$31+3M,FS

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193 FRAME1(1)=3H#FF2
194
195 FRAME1(5)=3H#F3
196 FRAME1(6)=3H#E8
197
198 FNAME1(7)=3H#E9
199 P1000=PLNGTP1000.0
200
201 COMMENT READ FREQUENCY RANGE TO BE USED
202 READ INPUT TAPE11+32,FREQ0,FREQM
203 92 FORMAT43PF33
204 COMMENT READ TAKE=0FF ANGLP RANGE TO BE USED
205 READ INPUT TAPE11+33,BETAL,BETAM
206
207 93 FORMAT19FT7.31
208 COMMENT STARV PAY TRACING POSITION OF PROGRAM
209 READ INPUT TAPE21+3301,CHNT
210
211 9301 FORMAT184
212 IF(NCHNT)>3004+3304+3302
213 9302 DO 933 1=3ANCHY
214 933 READ INPUT TAPE 11+3303+NFREQU11
215
216 3303 FORMAT179.11
217 3310. FREQ=FREQ0
218 34. 81F(FREQ-FREQ0) 35.99+3501
219 35 HTC .200
220 HTCA=.00
221 INTERP=.1
222 LL=0
223 IF1(PEN) 11501+36.11501
224
225 36 SPEN=1
226
227 BETA=BETAL
228
229 37 1F(BETA=BETAM) 98.38.9001
230
231 COMMENT CALCULATE CONSTANTS FOR A GIVEN BETAY
232 38 BETAREGBD=BETAI
233 COSBRCOSPI=BETAR
234 DANGLE=3.4625927+1BE3AR1.0.5701963
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225      60 J=J+1
226      GD TD 59
227      61 F01=TDFDIST(J-1)
228      FD2=TDFDIST(J)
229      DI=EDIST(J,J-1)
230      D2=EDIST(J,J)
231      FD=FC1+(TDIST-D1)/(D2-D1)*(FD02-FD1)
232      IF FO1 62.89+62
233      62 REFIND=(FREQ/FD)*COSSES
234      IF REFIND-1.0, 63.89+89
235      63 IRCT=IRCT+1
236      IF IRCT-10, 6301.6301+93
237      6401 LAYR=7
238      FLAYR=7.0
239      FMODE=FDDE*10+0-FLAYR
240      6401 LAYR=7
241      DR1=(R+H)*SIN(LANGES-ANGH1)/SIN(LANGE)
242      DD1R=(LANGE-ANGH1)
243      PDIST=PDIST+DP1
244      GDIST=GDIST+DN1
245      IF GDIST>P10001 66.66+93
246      64 IF IMCALC1 65.66+65
247      65 KK=KK+1
248      FIDIKK1=GDIST
249      FIMTIKK1=NMES
250      RMODE(IRCT)=NAME(LAYER)
251      66 GD TD 74
252      67 GD TO 89
253      COMMENT UP-GDING E LAYER
254      68 NM=HME
255      YM=YM
256      SHM=HM
257      69 IF IDIST-EDIST(J,J) 61.61+60
47 REFIND=(FREQ/FO)*COSSES
48 IF (REFIND-1.0) 48.68+68
49 IRCT=IRCT+1
50 IF (IRCT-10) 49.49+93
51 K=KK+
52 IF (KK)>GDIST
53 IF MES=0
54 GO TO 68
COMMENT DOWN-GDING FS LAYER
55 I=0
56 TOLST=GDIST+R*(ANGFS-ANGH1)
57 IF IDIST-PSTART(1) 58.5501+5501
58 J=1
59 IF IDIST-EDIST(J,J) 61.61+60

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ANGLE1=ANGLE          289      YM=YMWF1          321
COSI=COSSE          290      SHM=HM             322
H1=0.0               291      ANGLE1=ANGF1        323
LAYER=2              292      COSI=COSF1         324
FLAYR=2.0            293      H1=HMWF+YME       325
CALL CALCOIGN1ST+RANGE+TFOE+FO1    294      IF(IFRMES1 75+76+75
IFRMES=0              295      75 HM=MES           326
CALL UPREF            296      LAYER=3           327
IREFL=IREFL          297      CALL CALCFOG1ST+RANGF1+TFOF1+FO1
IF(IREFL=4) 69+93.69   298      328
CALL PATH             299      FLAYR=3.0          329
IREFL=IREFL          300      CALL CALCFOG1ST+RANGF1+TFOF1+FO1
COMMENT DOWN-GOING F LAYER          301      330
71 HM=HME             302      IF(IFRMES=0) 70+70+77
70 GO TO (89,74,76)+IREFL          303      331
YME=YME              304      77 CALL PATH
SHM=-HM              305      IREFL=IREFL
COMMENT DOWN-GOING F LAYER          306      332
79 HM=HM             307      CALL UPREF
ANGLE1=ANGLE          308      333
COSI=COSSE          309      ANGLE1=ANGF1        334
LAYER=6              310      COSI=COSF1         335
FLAYR=6.0              311      H2=HMWF2+YMWF2
CALL CALCOIGN1ST+RANGEF1+TFOE+FO1 312      LAYER=5           336
IFRMES=C              313      CALL DREF
CALL DWREF            314      337
IREFL=IREFL          315      TOIST=GDIST+(ANGF1-ARCSIN((C1BR/(H2+R))) )
IF(IREFL=4) 72+93+72   316      CALL CALCFOG1ST+TFCF1+FO1
72 CALL PATH          317      338
IREFL=IREFL          318      CALL DREF
IF(GDIST-P1000, 73+73+93 319      339
73 GO TO (74+54.56)+IREFL          320
COMMENT UP-GOING F1 LAYER          321
76 HM=HMWF1          322

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81 GO TO (82,71,71),IREFL
COMMENT F2 LAYER
 92 HMF2=0.0
  THMF2=100.0
TO1STGO1ST
  TRANGE=0.0
  ICNT=0
  ANGH1=A*CSIN(COSBR/(R*(HMF1)))
  83 IF(ABSF/THMF2-HMF2)=10.D1 86.86.84
  84 IF(11CNT=20) 85.05.93
  85 HMF2=THMF2
CALL CALCFOTDIST.THT.THMF2
  ANGH2=ARCSINF(COSBR/(R+THMF2))
T01ST=T01ST-TRANGE
  TRANGE=R*(ANGH1-ANGH2)
  TDIST=T01ST+TRANGE
  ICNT=ICNT+1
  GO TO 83
  86 HMF2=THMF2
  ANGP2=ARCSINF(COSBR/(R+HMF2))
  COSF2=COSE(ANGF2)
  YM=YMFP2
  YMFP2=(0.4/1.4)*HMF2
  HM=HMF2
  SHM=HM
ANGLE1=ANGSF2
  H1=HMF1+YMFP1
  LAYR=4
  FLAYR=4.D
CALL CALCFOTDIST.TFOF2,FO
  REFINO=(FREQ/FO)*COSF2
  IF(REFIND<1.0) 87.93.93
  88 IF(REFIND>1.0) 87.93.93

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353
  87 IREFL=1
    H2=HMF2-YMF2
    CALL PATH
    REFL=IREFL
    IF(IGO1ST=1DD0) 88.00.93
    88 GO TO (79,93,93),IREFL
COMMENT TRACE RAY TO GROUND
  354
    89 H)=0.D
    H2=HMF-YMF
    IREFL=3
    LAYR=8
    CALL PATH
    INTRP:INTERP
    IF(CDIST-P1000)< 30.90.53
    90 IF(RADIST-(PLENGT-1000.0)) 3801.91.91
    91 GO TO (92,1D0),INTERP
    92 1PE4=0
    LL=LL+1
    AGDIST(LL)=GDIST
    AREPA(LL)=BETA
    AWP(LL)=FNODE
    GO TO 3601
    93 GO TD (54,1D0),INTERP
    94 BETA=BETA+BETAD
    GO TO 37
    9401 00 95 8=1,10
    95 RMONE(1)=6C6160666060
    11*1
    HTCALC=1
    IF(INCT1)<52.051.952
    951 HTCAL=0
    GD TO 9501
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449 HOLD(IKL)=GDIST
450 HOLD(IKL)=TIME
451 HOLD(IKL)=GDIST+PLENG
452 HOLD(IKL)=0B
453 FLONO=FLON
454 IF(IHCA1) 108,1085,108
455 IC8 WRITE OUTPUT TAPE 6,104,FHNAME
456 WRITE OUTPUT TAPE 6,105,PLENG,FLAT,FLONO,BER
457 WRITE OUTPUT TAPE 6,1081,RMODE(11,1=1,101,FREQ,BETA
458 1081 FORMAT(1Hn,SHMDE ,1CAL/H0,F*3*X,2HMC,5X,F7*3,1X,7HDEGREES)
459 WRITE OUTPUT TAPE 6,1082
460 1082 FORMAT(1Hn,2X,6HHEIGHT*3X,5H RANGE)
461 DO 1083 1J=LARK
462 1083 WRITE OUTPUT TAPE 6,1084,FIHT(1J),FD1T(1J)
463 1084 FORMAT(1Hn,FB*2*F10.2)
464 1085 DO 111 1=1,10
465 8 111 RMODE(11)=0606060606060
466 467 112 WRITE OUTPUT TAPE 6,113
468 113 FORMAT(1Hn,14H RAY PENETRATES)
469 114*1 WRITE OUTPUT TAPE 6,114,FHNAME
470 FLONO=FLON
471 WRITE OUTPUT TAPE 6,105,PLENG,FLAT,FLONO,BER
472 WRITE OUTPUT TAPE 6,116
473 MODE
474 116 FORMAT(1Hn, 99H
1 1 FREQ 97A DIST TIME DIFF DB1
475 DO 117 LK=1,KL
476 117 WRITE OUTPUT TAPE 6,118,(HOLD(ILK+1,1=1,10),HOLD(ILK),HOLD(ILK))
477 2HOLD(ILK),HOLD(ILK),HOLD(ILK)
478 118 FORMAT(1Hn,10A6,F6.2,F6.2,F9.2,F6.2,F7.2)
479 GO TO 1
480 END
HOLD(ILK)=BETA

```

SEL-63-103

## IONOSPHERIC PROFILE FOR 6 OCTOBER 1962 1737.36 GMT PAHOA/BEAUFORD PATH

FOE	F0F1	F0F2	HT F0F2	RANGE	2.9	4.0	7.6	232.37	2800.00	3.1	4.4	7.7	250.19	580.00
3.3	4.6	7.5	205.55	0.	2.9	4.0	7.5	231.35	2900.00	3.1	4.4	7.7	252.39	5900.00
C.	0.	7.5	207.13	100.00	2.9	4.0	7.5	230.27	3000.00	3.1	4.4	7.7	254.49	6000.00
0.	0.	7.5	208.93	200.00	2.9	4.1	7.5	229.14	3100.00	3.1	4.4	7.8	256.48	6100.00
C.	0.	7.5	210.97	300.00	2.9	4.1	7.5	227.76	3200.00	3.1	4.4	7.8	258.36	6200.00
C.	0.	7.5	213.23	400.00	2.9	4.1	7.5	224.88	3300.00	3.1	4.4	7.8	262.13	6300.00
C.	0.	7.6	215.73	500.00	2.9	4.1	7.5	222.06	3400.00	3.1	4.4	7.8	261.79	6400.00
0.	0.	7.6	218.45	600.00	3.0	4.1	7.5	216.67	3500.00	3.1	4.4	7.8	266.26	6500.00
0.	0.	7.6	221.39	700.00	3.0	4.2	7.5	213.09	3700.00	3.1	4.4	7.8	267.80	6700.00
0.	0.	7.6	224.57	800.00	3.0	4.2	7.5	210.77	3500.00	3.2	4.4	7.9	269.70	6800.00
0.	0.	7.6	229.28	900.00	3.0	4.2	7.5	219.20	3900.00	3.2	4.4	7.9	263.96	6900.00
2.5	3.6	7.6	233.33	1000.00	3.0	4.2	7.5	220.97	4000.00	3.2	4.4	7.9	268.57	7000.00
2.6	3.6	7.6	236.64	1100.00	3.0	4.2	7.5	222.05	4100.00	3.2	4.4	7.9	267.55	7100.00
2.6	3.6	7.6	239.19	1200.00	3.0	4.2	7.5	222.96	4200.00	3.2	4.4	7.9	265.49	7200.00
2.6	3.7	7.6	241.71	1300.00	3.0	4.2	7.5	223.90	4300.00	3.2	4.4	7.9	263.96	7300.00
2.6	3.7	7.6	242.87	1400.00	3.0	4.2	7.5	224.85	4400.00	3.2	4.4	8.0	262.29	7400.00
2.6	3.7	7.6	242.39	1500.00	3.0	4.3	7.5	225.95	4500.00	3.2	4.4	8.0	263.78	7500.00
2.7	3.7	7.6	241.97	1600.00	3.0	4.3	7.6	225.95	4600.00	3.2	4.4	8.0	259.41	7600.00
2.7	3.8	7.6	242.79	1700.00	3.1	4.3	7.6	227.88	4700.00	3.2	4.4	8.0	258.29	7700.00
2.7	3.8	7.6	243.30	1800.00	3.1	4.3	7.6	224.93	4800.00	3.2	4.4	8.0	257.15	7800.00
2.7	3.8	7.6	243.33	1900.00	3.1	4.3	7.6	230.91	4900.00	3.2	4.4	8.1	256.25	7900.00
2.8	3.9	7.6	240.50	2200.00	3.1	4.3	7.7	232.97	5000.00	3.2	4.4	8.1	255.50	8000.00
2.8	3.9	7.6	242.87	2000.00	3.1	4.3	7.7	239.36	5400.00					
2.8	3.9	7.6	238.58	2300.00	3.1	4.3	7.7	241.45	5400.00					
2.8	3.9	7.6	235.18	2400.00	3.1	4.3	7.7	243.52	5500.00					
2.8	3.9	7.6	235.12	2500.00	3.1	4.4	7.7	244.58	5600.00					
2.8	4.0	7.6	234.25	2600.00	3.1	4.4	7.7	247.67	5700.00					
2.8	4.0	7.6	233.34	2700.00										

6 OCTOBER 1962 1737.36 GMT PAHOA/8E0FORD PATH

PATH LENGTH	8045.35 KM	TX LAT	19.50 0EG	TX LONG	-154.95 DEG	RX BEARING	56.26 DEG		
MODE				FREQ	BETA	DIST	TIME	DIFF	OB
.E	.E	.E	.E	4.00	1.18	8039.09	27.10	-6.26	649.57
.F2	.E	.E	.E	4.00	13.19	8041.41	27.98	-3.94	894.86
.E	.E	.E	.E	5.00	1.22	8037.90	27.09	-7.45	417.28
.E	.E	.E	.E	6.00	1.28	8036.66	27.09	-8.69	290.56
.E	.E	.E	.E	7.00	1.35	8035.48	27.09	-9.87	213.86
.F2	.E	.E	.E	7.00	12.50	8026.50	27.86	-18.85	275.91
.E	.E	.E	.E	8.00	1.44	8034.57	27.69	-10.78	163.91
.E	.E	.E	.E	9.00	1.56	8034.34	27.10	-11.01	129.54
.E	.E	.E	.E	10.00	1.68	8035.43	27.12	-9.92	104.85
.F2	.F2	.F2	.F2	10.00	23.19	8019.76	30.17	-29.59	66.07
.E	.E	.E	.E	11.00	1.85	8039.26	27.16	-6.09	86.48
.F2	.F1	.F1	.F1	11.00	13.20	7989.22	28.10	-56.13	60.34
.F2	.F2	.F2	.F2	11.00	21.70	8024.14	29.87	-21.17	57.77
.F2	.F2	.F2	.F2	11.00	24.17	8041.84	30.53	-3.51	60.41
.F1	.E	.E	.F	12.00	7.01	8043.03	27.63	-2.32	71.98
.F2	.F2	.F2	.F2	12.00	18.43	8021.89	29.23	-23.46	47.56
.F2	.F2	.F2	.F2	12.00	20.90	8040.18	29.80	-5.17	50.14
.F2	.F2	.F2	.F2	12.00	23.91	8042.95	30.48	-2.40	51.30
.F2	.F2	.F2	.F2	13.00	15.03	8042.09	28.85	-3.26	39.52
.F2	.F2	.F2	.F2	13.00	17.66	8031.97	29.15	-13.38	41.96
.F2	.F2	.F2	.F2	13.00	20.65	8042.70	29.77	-2.65	43.22
.F2	.F2	.F2	.F2	13.00	26.35	8037.02	30.58	-8.33	43.13
.F2	.F2	.F2	.F2	14.00	14.17	8036.79	28.68	-6.56	35.63
.F2	.F2	.F2	.F2	14.00	17.32	8037.78	29.13	-7.57	36.79
.F2	.F2	.F2	.F2	14.00	20.86	8040.51	29.87	3.15	37.01
.F2	.F2	.F2	.F2	15.00	10.72	8018.50	28.16	-26.85	29.89
.F2	.F2	.F2	.F2	15.00	13.72	8033.63	28.57	-11.72	31.79
.F2	.F2	.F2	.F2	15.00	17.35	8042.26	29.18	-3.09	32.05
.F2	.F2	.F2	.F2	15.00	22.10	8045.07	30.17	-0.28	30.80
.F2	.F2	.F2	.F2	16.00	10.03	8044.89	28.24	-0.46	27.36
.F2	.F2	.F2	.F2	16.00	13.52	8036.26	28.56	-9.09	28.27
.F2	.F2	.F2	.F2	16.00	17.82	8047.48	29.33	2.13	27.63
.F2	.F2	.F2		17.00	6.29	8026.02	27.85	-19.33	22.57
.F2	.F2	.F2		17.00	9.66	8040.63	28.17	-4.72	24.79
.F2	.F2	.F2		17.00	13.56	8043.77	28.63	-1.58	25.01
.F2	.F2			18.00	0.26	8055.64	27.74	10.29	16.68
.F2	.F2			18.00	5.64	8046.42	27.92	1.07	20.88
.F2	.F2			18.00	9.49	8042.59	28.17	-2.76	22.35
.F2	.F2			18.00	13.91	8040.59	28.69	-4.76	21.95
.F2	.F2			19.00	0.28	8040.53	27.84	-4.82	19.12
.F2	.F2			19.00	9.51	8042.76	28.18	-2.59	20.05
.F2	.F2			19.00	15.25	8033.20	28.90	-12.15	18.44
.F2	.F2			20.00	5.08	8042.24	27.84	-3.11	17.45
.F2	.F2			20.00	9.73	8042.64	28.22	-2.71	17.89
.F2	.F2			21.00	5.02	8044.62	27.86	-0.73	15.90
.F2	.F2			21.00	10.22	8045.00	28.32	-0.35	15.80
.F2	.F2			22.00	0.09	8042.56	27.86	-2.79	14.45
.F2	.F2			23.00	5.29	8037.01	27.86	-7.54	13.09
.F2	.F2			24.00	5.66	8040.43	27.93	-4.92	11.79
.F2	.F2			25.00	6.71	8016.11	27.91	-29.24	10.27

6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH  
 PATH LENGTH 8045.35 KM TX LAT 19.50 OEG TX LONG -154.95 DEG RX BEARING 50.26 OEG  
 MODE .F1 .E .E .E  
 12.000 MC 7.005 DEGREES  
 HEIGHT RANGE  
 140.00 753.85  
 187.17 1095.09  
 100.00 1928.36  
 0. 2512.50  
 112.74 3228.64  
 0. 3944.77  
 110.03 4632.49  
 0. 5326.21  
 110.00 6006.97  
 0. 6687.74  
 109.73 7365.38  
 0. 8043.03

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6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH  
 PATH LENGTH 8045.35 KM TX LAT 19.50 OEG  
 MODE .F2 .F2 .F2 .F2  
 12.000 MC 18.426 DEGREES  
 HEIGHT RANGE  
 140.00 377.77  
 169.34 480.10  
 150.00 558.15  
 100.00 682.74  
 0. 960.20  
 140.00 1353.26  
 189.43 1599.69  
 150.00 1822.38  
 100.00 1964.47  
 0. 2241.93  
 140.00 2638.68  
 179.96 2893.49  
 150.00 3124.21  
 100.00 3269.73  
 0. 3547.19  
 140.00 3947.12  
 174.68 4222.29  
 150.00 4473.56  
 100.00 4621.89  
 0. 4899.35  
 140.00 5301.74  
 193.95 5655.36  
 150.00 5937.47  
 100.00 6137.81  
 0. 6415.27  
 140.00 6619.16  
 204.79 7218.02  
 150.00 7593.56  
 100.00 7744.43  
 0. 8021.89

6 OCTOBER 1962 1737.36 GMT PAHOA/REDFORD PATH		TX LONG -154.95 DEG RX BEARING 50.26 DEG		6 OCTOBER 1962 1737.36 GMT PAHOA/BEDFORD PATH		TX LONG -154.95 DEG RX BEARING 50.26 DEG	
PATH LENGTH	TX LAT	TX LAT	TX LONG	PATH LENGTH	TX LAT	TX LAT	TX LONG
MODE	F2	F2	F2	MODE	F2	F2	F2
12.000 MC	20.904 DEGREES			12.000 MC	23.913 DEGREES		
HEIGHT	RANGE	HEIGHT	RANGE	HEIGHT	RANGE	HEIGHT	RANGE
140.00	335.66	140.00	293.76	140.00	173.20	398.66	
170.63	437.73			150.00	484.11		
150.00	517.86			100.00	583.39		
100.00	630.00			0.	797.36		
0.	875.45			140.00	1091.12		
140.00	1221.78			192.22	1284.51		
192.09	1437.13			150.00	1458.78		
150.00	1630.90			100.00	1566.10		
100.00	1755.06			150.00	2459.57		
0.	2000.51			100.00	2568.11		
140.00	2349.05			0.	2782.07		
185.51	2566.21			140.00	3085.53		
150.00	2761.59			182.28	3270.43		
100.00	2887.79			150.00	3435.88		
0.	3133.23			100.00	3545.43		
140.00	3483.69			0.	3759.39		
172.86	3687.70			140.00	4063.79		
150.00	3869.37			181.43	4253.98		
100.00	3997.23			150.00	4424.74		
0.	4242.68			100.00	4535.11		
140.00	4594.63			0.	4749.08		
182.54	4833.54			140.00	5054.20		
150.00	5050.80			193.38	5272.78		
100.00	5179.98			150.00	5472.17		
0.	5425.43			100.00	5583.17		
140.00	5778.50			0.	5797.13		
203.42	6074.58			140.00	6102.78		
150.30	6349.59			211.32	6361.74		
150.00	6479.62			150.00	6601.56		
100.00	7794.74			100.00	7717.57		
0.	8040.18			0.	8942.95		

6 OCTOBER 1962 1737.36 GMT PANDA/BEDFORD PATH		6 OCTOBER 1962 1737.36 GMT PANDA/BEDFORD PATH	
PATH LENGTH	TX LAT	TX LONG	RX BEARING
8045.35 KM	19.50 DEG	-154.95 DEG	50.26 DEG
MODE . F2	. F2	. F2	. F2
17.000 MC	6.286 DEGREES	17.000 MC	9.659 DEGREES
HEIGHT	RANGE	HEIGHT	RANGE
140.00	795.34	140.00	625.52
140.00	1164.93	182.75	825.41
188.09	1494.02	150.00	989.93
150.00	1755.57	100.00	1199.92
100.00	0.	0.	1674.83
140.00	2376.09	140.00	2328.72
140.00	3229.29	185.03	2463.34
169.62	3636.69	150.00	2962.70
150.00	4001.77	100.00	3181.45
100.00	4285.17	0.	3656.36
0.	4905.69	140.00	4318.01
140.00	5777.34	181.36	4680.38
208.33	6457.01	150.00	5007.72
150.00	7109.07	100.00	5232.91
100.00	7405.51	0.	5707.82
0.	8026.02	140.00	6374.27
		213.76	6875.11
		150.00	7337.97
		100.00	7565.72
		0.	8040.63

6 OCTOBER 1962 1737.36 GMT PAHOA/HONFORD PATH  
 PATH LENGTH 8045.35 KM TX LAT 19.5N 0EG  
 MODE •F2 •F2 •F2 •F2  
 17.000 MC 13.565 DEGREES  
 HEIGHT RANGE  
 140.00 490.10  
 181.88 678.10  
 150.00 836.21  
 100.00 1003.83  
 0. 1368.75  
 140.00 1873.05  
 197.43 2178.60  
 150.00 2455.21  
 100.00 2626.44  
 0. 2991.36  
 140.00 3498.91  
 178.46 3763.34  
 150.00 3997.72  
 100.00 4171.56  
 0. 4536.50  
 140.00 5044.28  
 198.22 5380.95  
 150.00 5686.20  
 100.00 5861.86  
 0. 6226.78  
 140.00 6337.46  
 217.70 7135.07  
 150.00 7502.65  
 100.00 7678.85  
 0. 8043.77

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